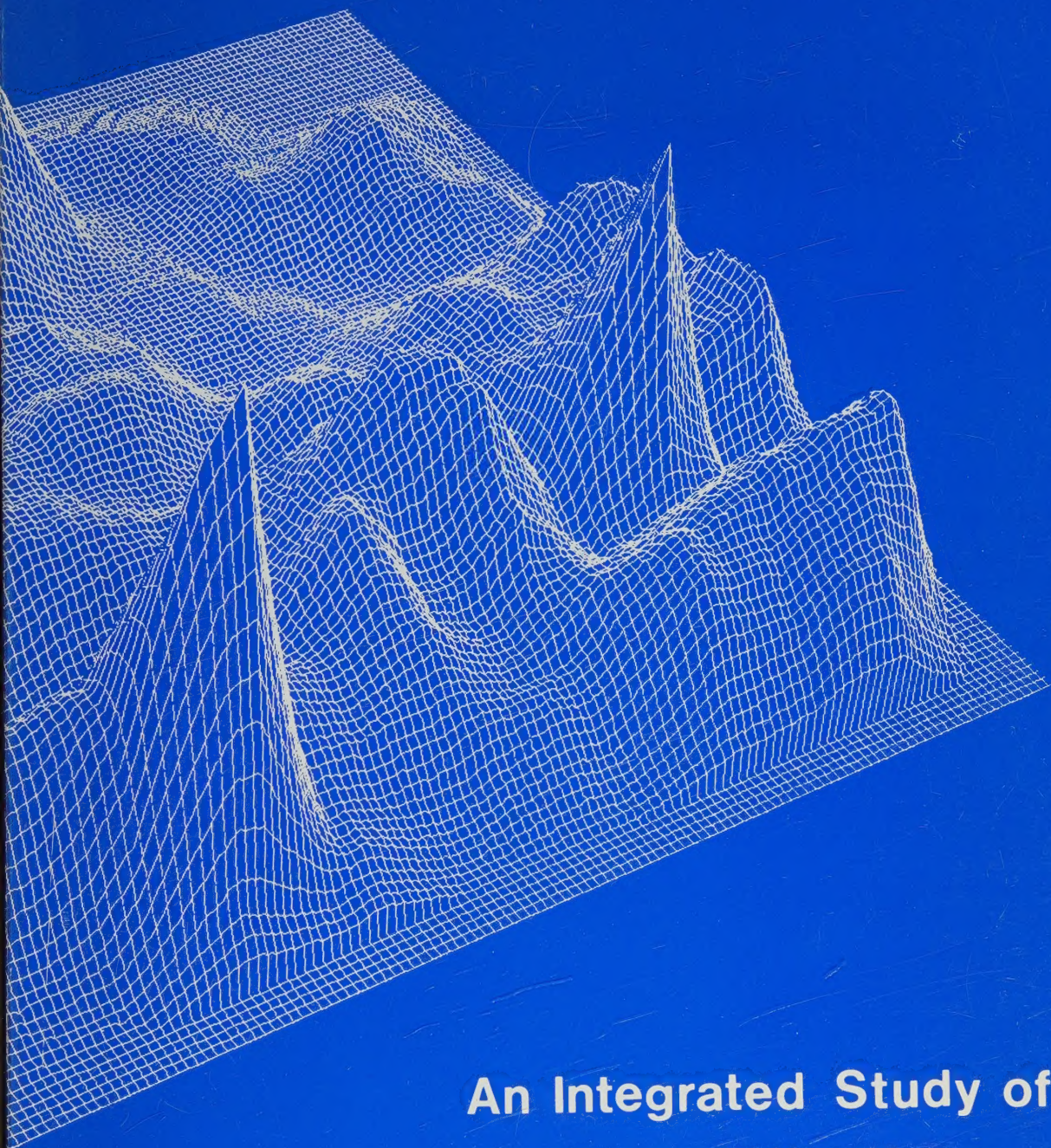


MEDDELANDEN FRÅN LUNDS UNIVERSITETS GEOGRAFISKA INSTITUTION
AVHANDLINGAR XCVIII



An Integrated Study of Desertification

by

Lennart Olsson

Diss. Lund

1985

MEDDELANDEN FRÅN LUNDS UNIVERSITETS GEOGRAFISKA INSTITUTION
AVHANDLINGAR XCVIII

An Integrated Study of Desertification

**Applications of Remote Sensing, GIS and
Spatial Models in Semi-Arid Sudan**

**by
Lennart Olsson**



1985

THE UNIVERSITY OF LUND, SWEDEN
DEPARTMENT OF GEOGRAPHY

Author's address:

Department of Physical Geography
University of Lund
Sölvegatan 13
S-223 62 Lund
SWEDEN

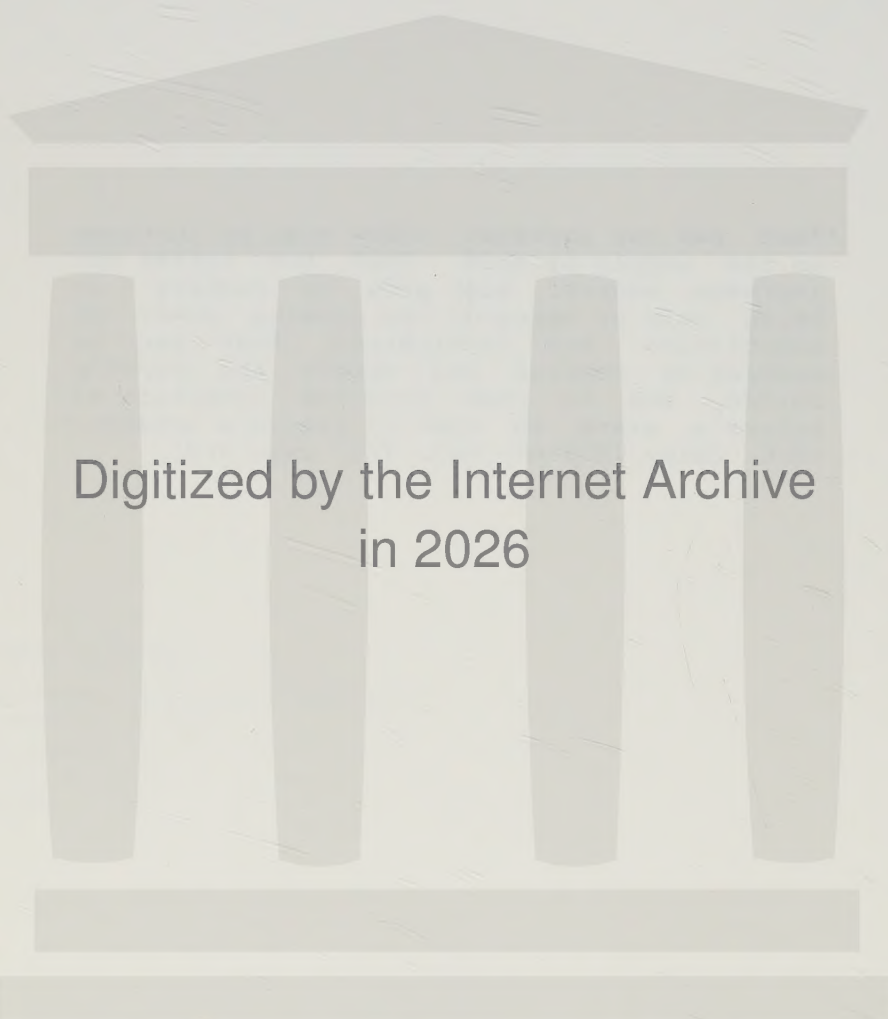
Copyright Lennart Olsson

ISBN 91-7222-975-6

Cover:

3-D image showing population density (inhabitants per sqkm) in the study area.

"That man may increase, there must be increase in the supply of food. That the latter may increase, mankind must grow in numbers - it being only by means of the growing power of association and combination, that man is enabled to control and direct the earth's forces, and to pass from the condition of nature's slave, to that of nature's master."
(H.C. Carey 1858-65, Vol. III, page 313)



Digitized by the Internet Archive
in 2026

https://archive.org/details/IA41552414_0076

Content:

Abstract	2
1. Introduction	3
2. The Kordofan Province and the Study Area	7
3. Approaches to Landscape Analysis	18
4. Remote Sensing	30
5. Geographical Information System (GIS)	69
6. Spatial Models of Land Use	75
7. Analysis of Climatic Conditions	97
8. Population and Land Use	121
9. Synthesis and Conclusion	134
Appendix	149
References	159

Abstract

The aim of this study has been twofold, to develop methodology for integration of remotely sensed data with ancillary data in raster as well as vector format, in a geographical information system, and to apply the methodology to the study of desertification in a study area in semi arid Sudan. Of special interest has been to investigate the relationships between natural and human factors in land degradation.

Field data and Landsat data have been used in combination with existing maps and statistics on climate, agriculture and population. Statistical analyses have revealed a significant negative trend in number of rainfall days, causing severe decrease in agricultural crop yield. Spatial models of land use have been applied to the study of potential agricultural production.

It has not been possible to verify the traditional concept of desertification as a continuous man-made process of environmental degradation. Climatic conditions play a major role in controlling crop yield and the growth of natural vegetation.

one

Introduction

1. AIM OF THE STUDY

Originally the ambition of this thesis was to carry out an integrated investigation of desertification by means of conventional geographical methods, e.g. field work in a rather limited area, interpretation of air photos and Landsat images, analysis of soil composition, studies of old records on the environment during "pre-desertification time". However, with the acquisition of advanced equipment for digital image analysis (Dipix Aries II Image Analysis System) my ambitions gradually changed to be more and more oriented towards the application of the new technology on land degradation and environmental monitoring. It soon became clear that the new technology did not work properly. In fact, due to malfunction almost 50 % of the first two and a half years, little of the image analysis for this thesis was done using the equipment.

Instead I was forced to start programming in order to solve the image analysis problems I had. By that time, a number of pilot studies at the laboratory, Hellden (1979 & 1980) and Hellden & Stern (1980), had clearly demonstrated the poor results of conventional computer classification of Landsat data. My interest in computer cartography led me soon into the field of geographical information systems as a possible way of improving the utility of satellite remote sensing.

The aim of the thesis can now be split up into two parts:

1. To develop various remote sensing techniques in combination with ancillary information and spatial models in a geographical information system.
2. To apply these methods on the study of land degradation. Of special importance was the investigation of relationships between the natural factors and the human factors in land degradation.

2. THE CONCEPTS OF DESERTIFICATION AND LAND DEGRADATION

The degradation of arid and semi-arid lands has been a field of intensive research the last ten years. The Sahelian drought, usually specified in time to 1968 - 1974, highlighted the need for research on the interaction between man, vegetation, soil and climate. The UN conference on desertification (UNCOD) held

in Nairobi in 1977, contributed with a large number of scientific and national reports on desertification.

A discussion regarding terminology and definition of the degradation of arid and semi-arid lands preceeded the conference. The terms desert encroachment, desertization and desertification were all used more or less synonymously (Rapp 1974 and Rapp et. al. 1976). In this study I prefer to use the term desertification which has become the most accepted one of the three. However, a more adequate term is simply land degradation, which is much wider and does not relate to desert at all.

Several definitions of desertification have been proposed and used. One of the more specific and widely used definitions was proposed by Dregne (1976): "the impoverishment of arid, semi-arid and some sub-humid ecosystems by the combined impact of man's activities and drought. It is the process of change in these ecosystems that can be measured by the reduced productivity of desirable plants, alterations in the biomass and diversity of the micro and macro flora and fauna, accelerated soil deterioration and increased hazards for human occupancy". A shorter definition was proposed by Rapp (1974) and this definition was finally accepted as the official UN one at UNCOD: "the spread of desert-like conditions in arid or semi-arid areas, due to man's influence or to climatic change."

Implicit in the term desertification lies, however, the transformation of non-desert land into desert. This is not adequate in many cases. A desert is, according to Moore (1974) "an almost barren tract of land in which the precipitation is so scanty or so spasmodic that it will not adequately support vegetation". An area subject to desertification outside the true desert can hardly be considered as a desert until it has been proven that absence of vegetation is a fairly stable state, and not only part of a short-term fluctuation. Therefore, I would prefer to use the more neutral term land degradation, with the much more general definition:

the long-term decrease of the land's biological productivity caused or accelerated by human activities in combination with climate.

3. PREVIOUS STUDIES

In order to investigate the possibilities of using Landsat MSS data for environmental monitoring in arid and semi-arid regions, a number of pilot studies were carried out in different ecological zones in the Sudan, Kenya and Tunisia (Hellden 1978, Hellden 1980, Hellden & Stern 1980). Based on these experiences and on discussions with scholars from Sweden, Tanzania, Kenya, the Sudan and Tunisia a research project was launched, titled "Regional Studies of Desertification and its Control". Within the frames of this project, several subprojects were started.

This thesis is the final report from the sub-project

"Monitoring the Impact of Rainfed Agriculture and Grazing on Desertification". Previous reports on this project are: Olsson & Stern (1981), Olsson (1982), Hellden et.al. (1982), Olsson (1983), Olsson (1984 c & d), Olsson (1985) and Olsson et. al. (1985).

4. REMARKS ON DATA ANALYSIS

Data analyses in the thesis have been carried out using several different analysis facilities.

Conventional image analysis, e.g. destriping and other radiometric preprocessing, resampling and multispectral classification have mainly been carried out using a DIPIX Aries II Image analysis system at the Remote Sensing Laboratory.

Integration of image data and ancillary information, development of spatial models and the integration of vector with raster data have been done on a Sperry 1100/80 mainframe computer at the Lund University Computing Centre. A software package, DIAPAC (Olsson 1984a), containing conventional image analysis routines, texture transformations, spatial models, routines for integration of vector with raster data and image plotting (2, 3 and "4" dimensional) on different hard copy devices (B/W matrix printers and ink jet plotters), were developed in cooperation with Stefan Pinzke and Mikael Stern. Some of the programs make use of subroutines from the program packages UNIRAS (ESC 1984) and NAG (1984).

Statistical analyses of other than image data have been carried out using the statistical packages MINITAB (Ryan et.al. 1982), GENSTAT (Alvey et. al. 1977) and the general numerical package NAG (1984). For plotting of results, the general graphical package GD3 (Miller 1976) and to some extent NAG has been used in combination with penplotters.

5. ACKNOWLEDGEMENTS

The work has been sponsored by several agencies. The main financial support came from Swedish Agency for Research Cooperation with Developing Countries (SAREC) and Swedish Board for Space Activities (DFR).

Many people have contributed to the completion of this thesis, not all of them can be mentioned here. I must however express special thanks to some persons.

To Mikael Stern, my former colleague, who has been involved in most steps of the work, from field work in the Sudan to the final preparation of the thesis. Many great ideas have emanated from him.

To Ulf Hellden, my supervisor, who has followed my work from the start, in the field as well as in the laboratory. It has

been a continuous fruitful discussion.

To Anders Rapp, head of the department, who has inspired and encouraged me during the time.

To J.O. Mattson for reading and giving valuable comments on parts of the manuscript.

To Stefan Pinzke and Richard Nielsen, who have been of irreplaceable help in all kinds of computer problems.

To my colleagues at the Department of Physical Geography who have contributed to a stimulating and creative research environment.

To Siddig Awadallah and Mustafa Khogali at the Department of Geography, University of Khartoum who have inspired and assisted me during visits to the Sudan.

To Osama Abdel Gadir and Abdul Rahman at the Geography Department, University of Khartoum, who have accompanied me during field work. Thanks to them, the field work periods have been successful, interesting and pleasant.

To Ali Darag and his staff at the Range and Pasture Administration, Khartoum, with whom I have had many fruitful discussions.

To Peter Jönsson, Rezső Laszlo and Ulrik Mårtenson, who assisted me in the preparation of figures, and Bengt Oreström for correcting my English.

Finally I would like to express my warmest gratitude to the Sudanese people who have received me and my colleagues with a great hospitality in the numerous villages and towns we have visited.

two

The Kordofan Province and the Study Area

1. THE KORDOFAN PROVINCE

The Kordofan Province stretches from the desert in the north to the sub-humid savanna in the south. Several climatic, geological, geomorphological and vegetation zones are included, as

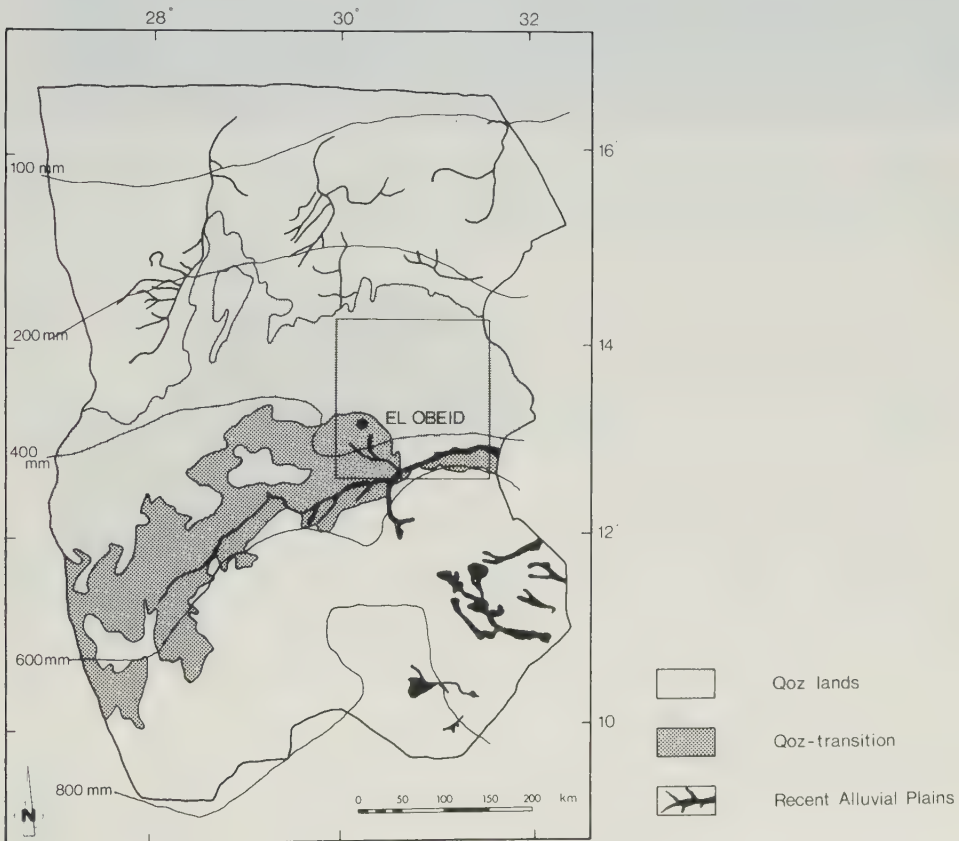


Fig. 2.1. Map showing the Kordofan Provinces. The frame indicates the study area, corresponding to the Landsat (1 - 3) World Reference System row: 187, path: 51. Modified from Pacheco & Dawoud (1976).



Fig. 2.2A. View from Jebel Gehaniya (Lat: 14 25', Long: 30 29') in February 1980. The cleared and harvested fields contrast sharply with the natural grass vegetation.

well as different land use systems. Fig. 2.1 gives a general overview of Northern and Southern Kordofan Provinces. The most characteristic landscape feature of Northern Kordofan is the Qoz region. This is a vast eolian deposition stretching from the Nile to the east through Kordofan and Darfur and continues into Tchad.

Two different modes of livelihood, pastoral animal husbandry and sedentary cultivation, have evolved in different parts of the province during a long time. The physical environment (climate and soils) has made different ways of using the land necessary. Socio-economic changes and climatic fluctuations during the last decades have brought substantial changes in land use pattern to the province, one example is shown in Fig. 2.2 A & B.

According to Horowitz (1981), "The social factors leading to desertification are of recent origin, as evidenced by the fact that the affected areas have previously sustained human populations for very long periods of time without serious degradation despite the recurrence of deficient rainfall ...". The two most important factors are viewed to be the rapid increase in the human population, and the massive intrusion of external demands on the local economy. Population estimates from different sources are shown in Tab. II.1.



Fig. 2.2B. View from the same spot in February 1984, note the fenceline and the tree indicated. The cultivated fields had been abandoned for many years and the natural grass vegetation was totally removed. The bush vegetation had suffered from low rainfall and heavy grazing.

The older estimates are not based on proper censuses, but are only personal estimates, and must therefore be regarded as rather dubious. The two estimates 1955/56 and 1973 are however

Tab. II.1 Population estimates, in millions of inhabitants, from different sources.

YEAR		TOTAL	RURAL	REFERENCE
1874	(NK)	0.2	-	Prout (1877)
1882	(NK)	1.9	-	Born (1965), ref to Krämer (1938)
1900	(NK)	0.6	-	Born (1965), ref to Krämer (1938)
1955/56	(K)	1.8	1.7	Dept. of Statistics, Sudan (1980)
1973	(K)	2.1	1.8	Dept. of Statistics, Sudan (1980)
1976	(K)	-	3.6	Watson et.al. (1976 & 1977)

(NK) = Northern Kordofan

(K) = Northern and Southern Kordofan together

(modified from Hellden 1984)

based on proper censuses, although of questionable accuracy (Stern 1984 & 1985), while the latter one is based on aircraft reconnaissance flights. The population increase is difficult to estimate due to the poor accuracy of the data and the fact that the figures emanate from different types of investigations. The population increase in the rural areas (column 2 in Tab. II.1) from the 1955/56 census to the aircraft inventory of 1976 was approximately 5 % annually, but the figure must be considered very inaccurate. Figures indicating a population increase as low as 1 percent, presented by Hellden (1984) are however based on erroneous data. Stern (1985) compiled data from the 1973 and the 1983 censuses on the Beredia Rural Council (the council where El Obeid is situated), and found that the total population increase was 2.70 % annually. This must be considered as a more realistic rate of increase than 5 % annually.

Judging from the population increase one would expect the area under cultivation to increase at approximately the same rate. Up to the early seventies, the cultivated area increased rapidly, see Fig. 2.3. With the exception of sorghum, the

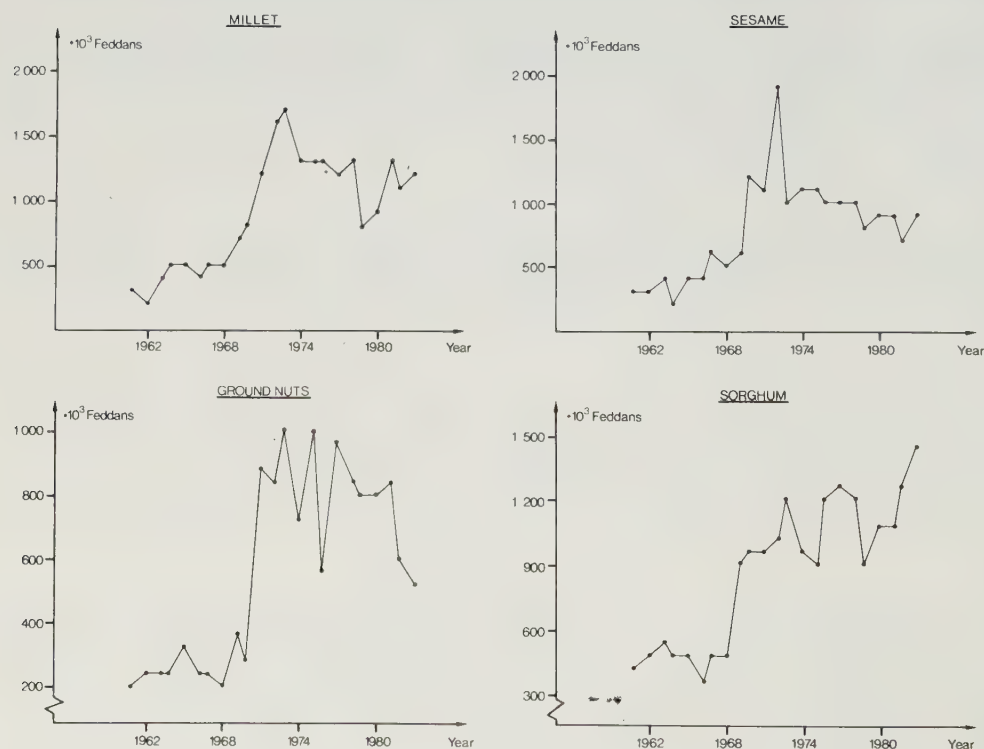


Fig. 2.3. Areas cultivated by the most important crops in Northern and Southern Kordofan provinces. Source: Statistics Division (1974, 1977 and 1984).

cultivated area has however decreased during the last ten years. The increase in cultivated area of sorghum took place mainly in Southern Kordofan.

Livestock breeding is another important land use factor. The figures for number of animals are very uncertain. In 1976/77, a comprehensive livestock survey was carried out (Watson et. al. 1976 & 1977). Figures for animal population before and after that survey must be considered as rough approximations only. In Fig. 2.4, the total livestock population in Northern and Southern Kordofan is shown for the period 1973 to 1979.

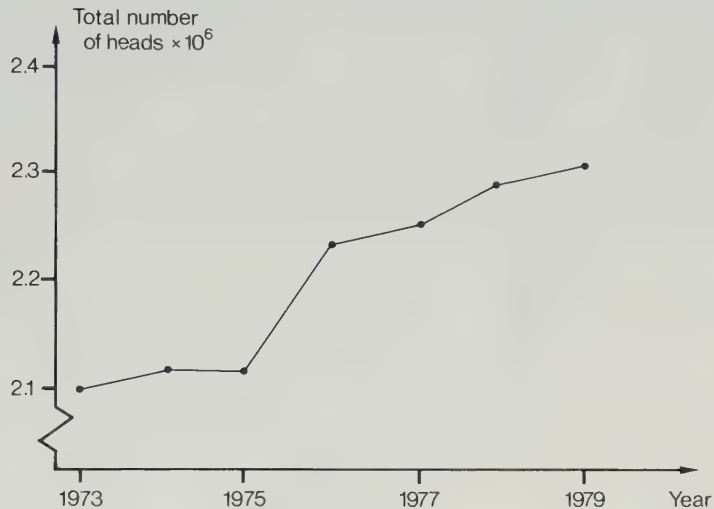


Fig. 2.4. Total livestock population (No. of heads of cattle, sheep, goats and camels) in Northern and Southern Kordofan provinces. Source: Statistics Division (1984).

A third important type of agricultural production is gum arabic, produced by the *Acacia senegal*. *Acacia senegal* grows on sandy soils in dry regions, between ca. 280 and 450 mm annual rainfall (Olsson K. 1984b), and is commonly a part of the traditional rain-fed cultivation cycle. The production of gum arabic has fluctuated very much over the last 20 years, see Fig. 2.5. It should be logical to assume the gum arabic production to increase when the cultivated area decreases. This can, however, not be verified by the very rough statistics available.

2. THE STUDY AREA

A study area in Northern Kordofan, equal to the Landsat MSS scene row 187, path 51, was chosen, see Fig. 2.1. The area is equal to 33 225 sqkm, and is covered by the topographical map sheets NC 36 M and NC 36 I. The original aim was to include

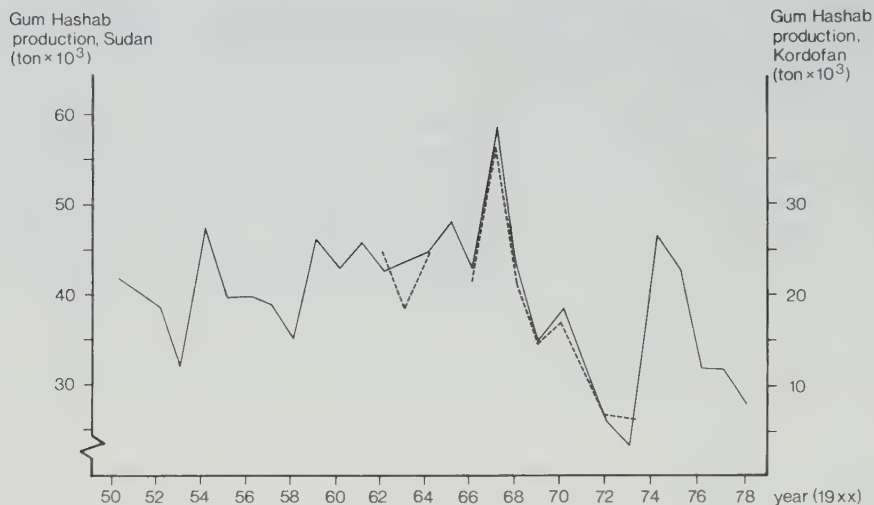


Fig. 2.5. Production of gum arabic in the Sudan (solid line) and Kordofan (dashed line) for the period 1950 to 1978. Modified from Olsson K. (1984a)

also the scene to the north of this (187/50), but appropriate satellite registrations were lacking. For the studies of climatic conditions the study area was however extended to cover the whole Kordofan province.

2.1 Natural Characteristics

Unless specially mentioned, this summary is based on information from the following reports: UNDP & FAO (1967), Salama (no year), Pacheco & Dawoud (1976) and Sandström (1984).

The two dominating geological formations are the basement complex and the Umm Ruwaba Series, see Fig. 2.6.

The basement complex comprises several types of chrystalline rocks, e.g. gneisses and granits. The rocks are generally deeply weathered and mostly covered by superficial deposits. Some major intrusive basement complex masses can be found in the southern and southeastern parts of the study area, e.g. Jebel Ed Dair.

From a ground water point of view, the basement complex is generally totally impermeabel, although weathering and faults can have created local aquifers. These aquifers have, however, mostly very limited capacity since the recharge is entirely dependent on rain water during the short rainy season. In areas where the basement complex is covered by fine textured soils, e.g. Gardud (see definition below), the recharge is slow due to the low infiltration capacity.

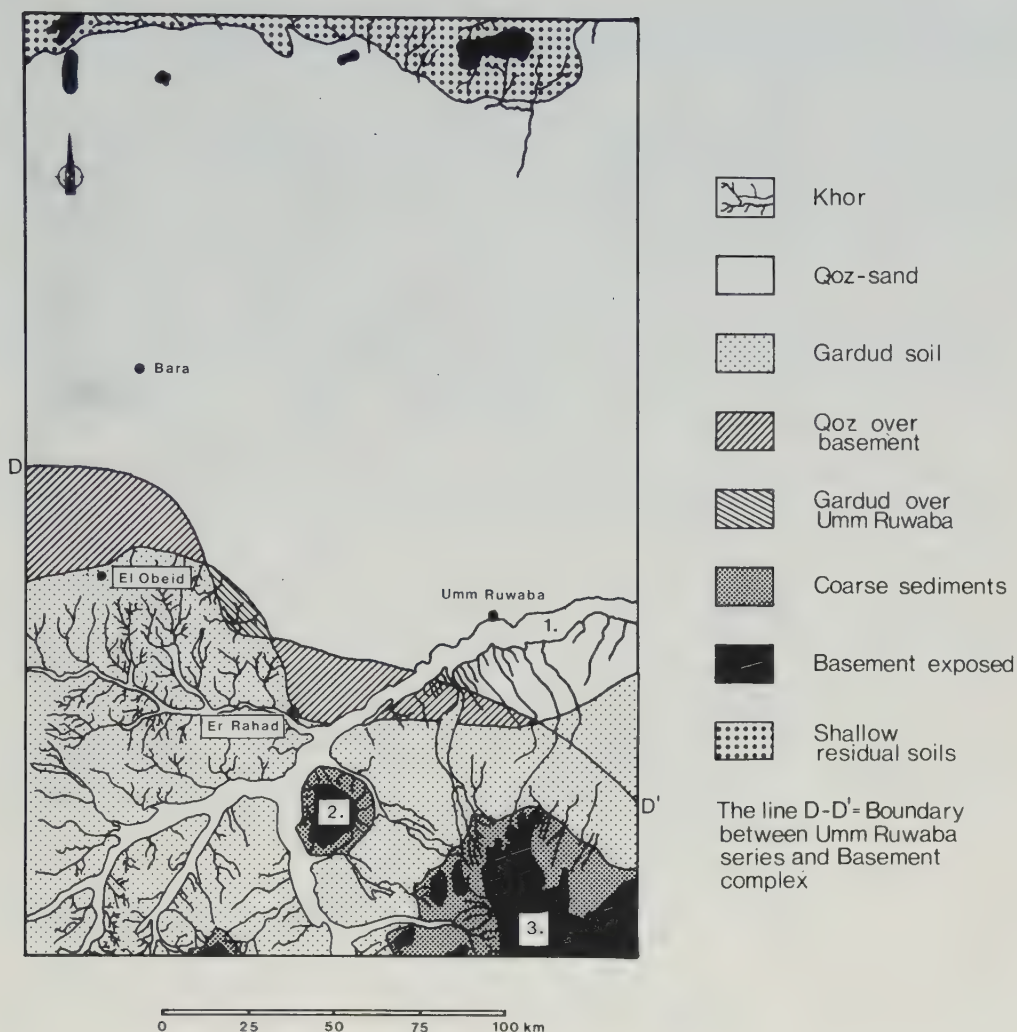


Fig. 2.6. Map showing geology, soil and geomorphology' of the study area (indicated by frame). 1. Khor Abu Hahl, 2. Jebel Ed Dair, 3. Nuba Mountains. Modified from Sandström (1984).

The Umm Ruwaba series comprises various fluvial and lacustrine sediments deposited on the often very undulating basement. The sediments are rather unconsolidated and seldom exposed. The thickness can reach 350 m in the eastern parts.

The Umm Ruwaba series is an excellent aquifer, the largest one is north of Khor Abu Hahl and covers ca. 70 000 sqkm. and has an average thickness of 350 m. The quality of the water is generally good, except for areas east of Umm Damm, where the water is brackish.

The distribution of soils of the study area are shown in Fig. 2.6. The soils can be divided into two main groups, Qoz soils and fine textured soils.

The Qoz is a vast eolian deposition, formed during the late Pleistocene. Warren (1970) distinguished between High Qoz and Low Qoz. The primary distinction of the Low Qoz is "that within it, dune forms are subdued, and indeed over much of the area cannot be distinguished at all" (ibid.). The High Qoz consists of much more distinct dune pattern, but no stream pattern.

Although the very low nutrient status and low water holding capacity the Qoz zone is intensively cultivated and generally densely populated. The loose structure of the soil makes it easy to cultivate without mechanized equipment, and facilitates the development of fine root systems of crops.

In the southern and south-western parts of the study area the dominating soils are more fine-textured and hard structured. Gardud soil is a group of non-cracking sandy clays. This soil is very difficult to cultivate without mechanized equipment.

The relief of the study area is, with the exception of a few inselbergs like Jebel Ed Dair, generally low and undulating in the Qoz area. The main drainage system is the Khor Abu Habl, flowing through the southern part of the study area.

The climate is semi-arid, with rainfall during three to four summer months, varying from 200 mm annual rainfall in the north to 350 mm in the south, see Fig. 2.5. Climatic conditions will be comprehensively analysed in Chapter 7.

The vegetation types follow the soil divisions fairly well, see Fig. 2.7. The Qoz sand is dominated by *Acacia senegal* savannah and the fine textured soils by *Acacia mellifera* thornland. A species that is dominating in some of the most densely populated areas is *Calotropis procera*, a species which is commonly assumed to be a key species of soils of very low fertility and areas subject to overexploitation.

2.2 Land Use

The whole study area is dominated by sedentary cultivators, see Fig. 3.6. Although most of the people practise a mixture of several different land use types, three main types of land use can be distinguished:

1. Rain-fed cultivation of mainly millet, sesame and ground nuts on the sandy soils. On more fine-textured soils sorghum is more common than millet. The cultivation is practised as shifting cultivation with tree fallow.
2. Grazing by traditional nomadic herds (mainly camels, sheep and goats), commercial nomadic herds (mainly cattle) as well as domestic animals belonging to the cultivators (mainly cattle, goats and donkeys).

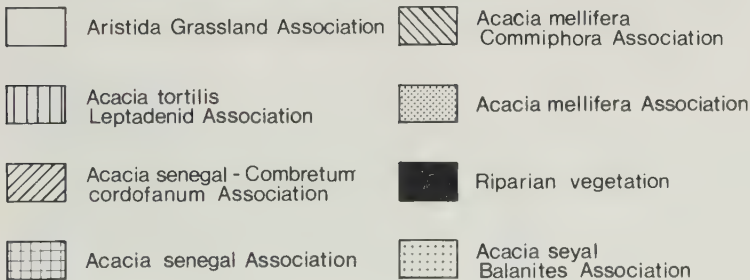
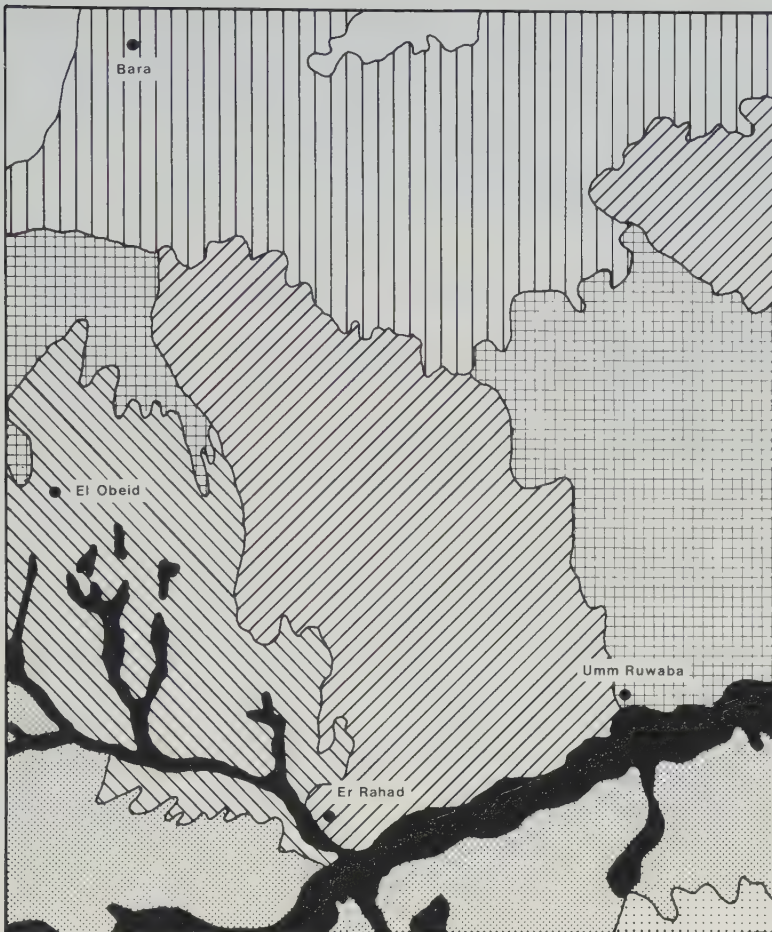


Fig. 2.7. Map showing the primary vegetation types in the study area. Modified from UNDP & FAO (1967).

3. Production of gum arabic from *Acacia senegal*. *Acacia senegal* is a much appreciated species not only for the gum production, but also as wood for fuel and construction, and the species is nitrogen fixating.

3. REPORTS ON DESERTIFICATION IN THE NORTHERN KORDOFAN PROVINCE

Numerous articles have been published over the years, describing and analysing the causes and effects of desertification in the province. A comprehensive plan for analyzing and counteracting desertification in the Sudan was published by the Sudan government in 1976, "Sudan's Desert Encroachment Control and Rehabilitation Programme (DECARP)".

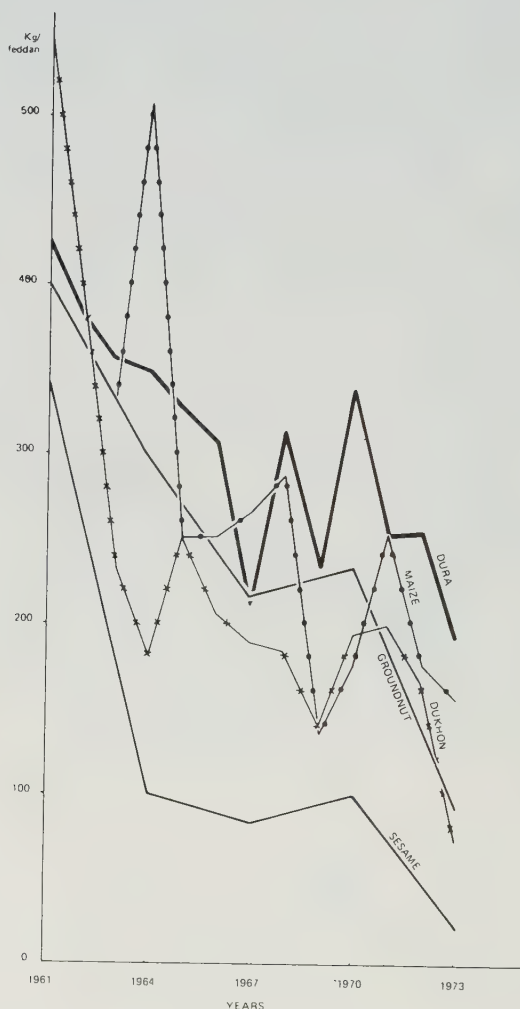


Fig. 2.8. According to DECARP (1976), "Declining productivity of major crops in the Kordofan Province due to desertification".

In the Sudan the term desert encroachment is more common than desertification, and is often described as an evil process, through which the desert moves southwards transforming productive land into desert. After a short reconnaissance flight over

parts of Northern Kordofan, Lamprey (1975) concluded "it is evident that the desert's southern boundary has shifted south by an average of about 90 - 100 km in the last 17 years." Shortly after this, DECARP (1976) wrote "surveys have shown that the desert had advanced 90 - 100 km within a 17 years period and is currently advancing at the rate of 5 to 6 km per year". In 1984, the same sources are quoted, e.g. Bayoumi (1984), which should mean that the whole province of Kordofan will be a desert within a few years' time. According to Eckholm & Brown (1977), "the spread of the Sahara has probably been measured most precisely in Sudan".

An example of desertification, commonly referred to, comes from DECARP (1976). The 1961 yield of major crops in the Northern Kordofan province was compared with the 1973 one, i.e. the best and the worst years, respectively, ever recorded, see Fig. 2.8. Still 10 years after, the same example is used (Grainger 1982), without any attempt to see what has happened after the Sahelian drought.

In a report on anthropogenic causes of desertification, Ibrahim (1978) compared the conditions around a village 20 km N of El Fasher on two occasions, 1954 and December 1968, through interpretation of aerial photos. Areas with millet fields in 1954 were in 1968 covered with dunes and sand sheets. He drew the conclusion that cultivation north of the agronomic dry boundary will result in desertification, i.e. former productive land will be transformed into desert. However, the study did not say anything about the conditions on later occasions, e.g. when the rainfall had improved after the Sahelian drought. It is impossible to say anything about trends by comparing the conditions on two occasions only.



three

Approaches to Landscape Analysis

1. INTRODUCTION

A number of different approaches to classification of arid and semiarid landscapes exist. The classification systems differ depending on the motives behind classification, the size of the area, the scale of the maps and the degree of accuracy.

It must be emphasized that the study of land degradation and desertification deals with a cultural landscape, i.e. a natural landscape modified and marked by human activities. The classification of landscape must be able to take both factors into consideration and express the relative importance of both human and natural features of the landscape.

From a remote sensing point of view the concept of land systems analysis is a very useful approach. The origins of this method come from three sources: The Division of Land Use Research, CSIRO Australia, the National Institute of Road Research, South Africa and MEXE, an experimental unit of the British Army. The experiences from the different activities were compiled and systematised in Brink et. al. (1966). Later experiences and developments are described in e.g. Dent & Young (1981), Vink (1975) and Townshend (1981a).

The Land Systems Approach is based on mapping units of the physical environment that can be seen in air photographs or satellite imagery. It can however easily be modified to treat the total environment, including human activities. A comprehensive treatment of different approaches is given in Vink (1975)

The combined effects of the natural landscape and its human activities make up a mosaic of different land systems, which becomes obvious by visual interpretation of images. This is the primary mapping unit defined as "an area with a recurring pattern of genetically linked land facets" (Brink et. al. 1966). The land system can be divided into a number of land facets, where the environmental conditions are more or less homogeneous. At this level, the human activities must play an important role in the classification. Tab. III.1 from Townshend (1981b) shows the nomenclature of different classification systems.

Tab. III.1. Approximate equivalence of areal subdivisions of landscape according to different classification systems.

<i>Bourne</i> (1931)	<i>Unstead</i> (1933)	<i>Isachenko</i> (1965)	<i>MEXE</i> (1965)	<i>Grant & Aitchinson</i> (1965)	<i>MEXE/ CSIRO</i> <i>Brink et al.</i> (1966)	<i>CSIRO</i> <i>Christian & Stewart</i> (1968)
site	feature	facies	land element	land component	land element	land element
region	stow	urocise	land facet	terrain unit	land facet	land unit
	tract	mestnost	recurrent land pattern	terrain pattern	land system	land system
tract group	okrug unterprovinz		land region land province	province	land region land province land division land zone	

(From Townshend 1981).

2. THE LARGE AREA DATA SAMPLING APPROACH (LADS)

2.1 Sampling Strategies

A landscape analysis approach, based on sampling in the field, was developed and described by Olsson & Stern (1981). The method is based on sampling strategies for collection of a wide range of environmental parameters over large areas. A number of different sampling designs have been applied by different researchers, random, stratified (geographical as well as geometrical), and systematic. The LADS method is based on a combination of geographically stratified, systematic and random sampling, a so-called road sampling. Fig. 3.1 shows the principles of different sampling designs.

Theoretically, the main principles of sampling of data are that the sample shall be random and representative of the whole population, see e.g. Cochran (1977). For practical applications on field data sampling there are however several restrictions on the use of proper random samples. Zonneveld (1972) emphasized the risk of over-representation of frequent classes when using strictly random sampling.

Most samples of field data must be considered as very small samples of the whole population, i.e. the entire land area. This implies that it is important to choose a sampling design that gives a good areal distribution. The cost and time for field work must also be taken into consideration when choosing sampling design.

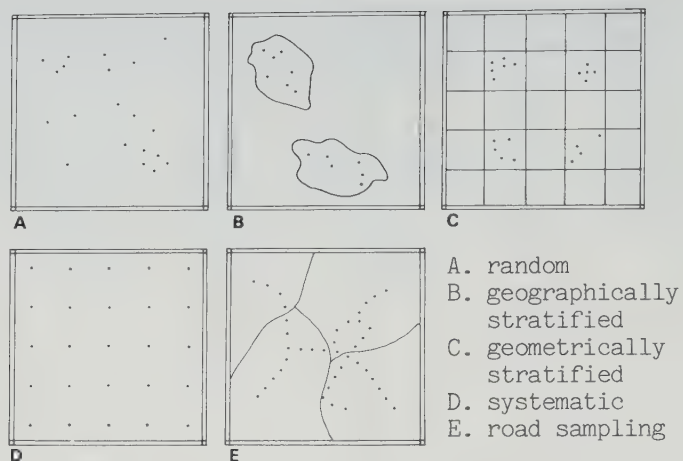


Fig. 3.1. Different sampling designs, from Olsson & Stern (1981)

Most researchers suggest stratified sampling to minimize bias and to keep the cost and time low. The area to be sampled can either be stratified geometrically, or geographically into landscape units. The area frame sampling methodology, developed by USDA (Houseman 1975), uses a geographical stratification based on air photos or satellite imagery. See Hanuschak & Morrissey (1977) and Hellden (1981 a & b) for demonstration of the use of Landsat imagery, combined with air photos and topographical maps, for construction of sampling frame.

2.2. Sampling Technique

The road sampling suggested by Olsson & Stern (1981) uses satellite imagery (Landsat) for stratification of the landscape. The procedure can be compared with the land systems analysis. A number of sites are then randomly selected in each stratum, see Fig. 3.2. The test sites shall be visited by travelling by car the shortest distance between them. Two different procedures for data collection are then followed.

1. High frequency sampling:

Along the road between the randomly selected sites, systematic sampling of environmental parameters are carried out every 500 or 1000 m. Prior to the sampling, the personnel must train themselves in estimating the different variables. After some practice the sampling can be carried out without stopping the car.

2. Low frequency sampling:

A low frequency sampling is carried out every 5 or 10 km, including collection of soil samples and actual measurements of different parameters.

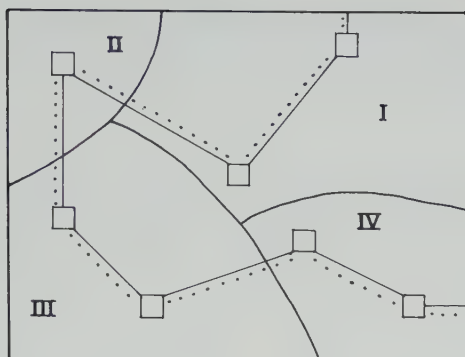


Fig. 3.2. The principle of road sampling. The areas I to IV are the different strata, according to interpretation of Landsat images. The squares represent randomly selected test sites, and the dots represent the field data points recorded in the high frequency sampling.

Tab. III.2 shows a summary of the different parameters collected by the two sampling procedures. In the Sudan, where the method has been tested several times, see e.g. Hellden & Olsson K. (1982), and Olsson (1984d), the average speed of sampling has been ca. 200 high frequency and 20 low frequency sampling points per day. Most of the times the sampling has been combined with interviews in villages.

Tab. III.2. Summary of the variables collected through LADS

HIGH FREQUENCY	LOW FREQUENCY
1. vegetation type	1. soil sample
2. cultivation type	2. description of soil pit
3. key species	3. pH-measurement
4. canopy cover	4. topography (slope gradient and length)
5. field cover	5. measurement of field cover
6. grazing intensity	6. measurement of canopy cover
7. macro relief	7. species diversity
8. micro relief	
9. soil colour	
10. erosion type	
11. erosion intensity	
12. soil type	

There are several drawbacks with this sampling technique.

1. biased sample because only passable roads can be followed
2. biased sample because only areas in the immediate vicinity of the road will be sampled
3. there is a risk that the observer takes too much consideration to features close to the car

4. misclassifications and faulty estimations can be made if the speed is too high.
5. the exact geographical position of each sampling point is difficult to determine

Some of the biases can be overseen and some can be minimized by proper training of the personnel. In the area where the technique has been tested the problem of road-bias is not severe. The area usually lacks any roads at all. Travelling takes place either between the villages "the route the crows fly" or along cattle tracks. Areas that will not be covered are mostly mountaineous and uninhabited and therefore of little interest in the land degradation context. Before the actual sampling starts, the personnel must train themselves in estimating the variables with caution taken to the problems mentioned above.

The most severe problem is the positioning of the sampling points. In order to minimize the positioning errors, a method of corrected dead reckoning was developed in cooperation with M. Stern, see Fig. 3.3.

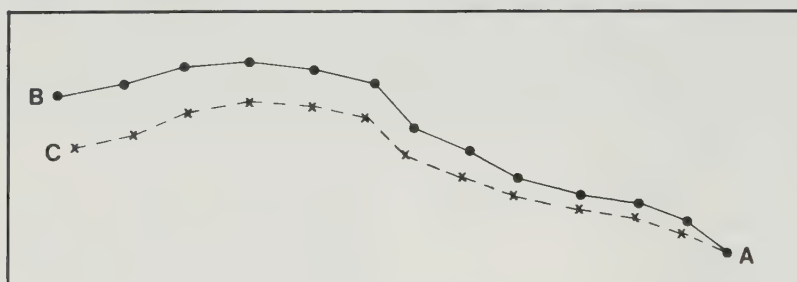


Fig. 3.3. Principle of the DEADREC procedure for correction of geographical positions through dead reckoning.

- A = start point where the geographical position is known
- C = end point after uncorrected dead reckoning from A
- B = correct end point where the geographical position is known
- x = uncorrected field data points
- = field data points after the DEADREC procedure

The sampling vehicle was supplied with a compass with a deviation table. The average direction was read every 500 m and noted in the protocol. Afterwards dead reckoning between points of known position was carried out through computer processing of the directions and the distances. As a result, the latitude and longitude of each sampling point could be determined. Estimations of the maximum and the average positioning errors indicated a maximum error, in areas very far from any point of known geographical position, of up to 6 km, and an average positioning error in the study area of 1 to 2 km. It

was, for example, in no cases possible to determine the position to a certain Landsat pixel.

3. DESCRIPTION OF SAMPLED PARAMETERS

Field data have been collected several times according to the recommendations given in Olsson & Stern (1981). These were however very ambitious and some simplifications have been done, especially regarding the low frequency sampling. The results from the low frequency sampling and test sites will not be comprehensively presented in this thesis. Below is a summary of the parameters collected by high frequency sampling used in this thesis. For a more detailed definition and description of the parameters, please refer to Olsson & Stern (1981).

1. Vegetation type (see also Fig. 3.4):

0 no natural vegetation

1 desert

Barren land, naturally devoid of vascular plants.

2 grassland

Land dominated by grasses and occasionally other herbs, sometimes with widely scattered or grouped trees and shrubs, the field cover of which does not exceed 2 %.

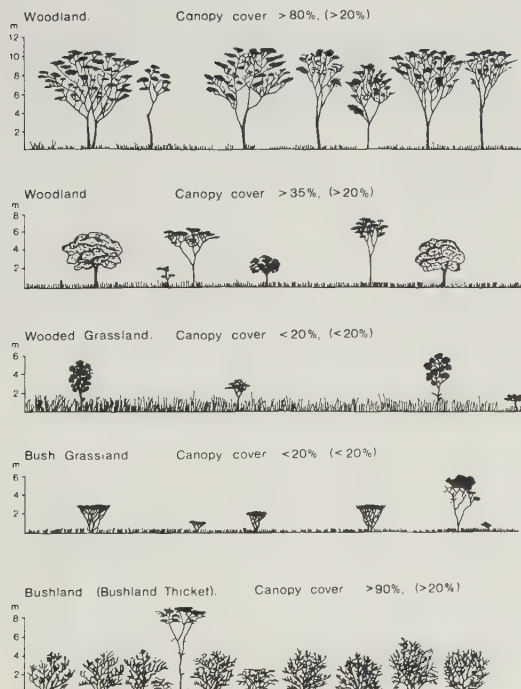


Fig. 3.4. Illustration of some vegetation classes. The first percentage number denotes the actual canopy cover of the given example, while the percentage within brackets denotes the minimum or maximum canopy cover according to the definition of the class. Source: Hellden 1980.

- 3 bush grassland
Grassland with scattered or grouped trees and shrubs, both always conspicuous. Shrubs dominate but combined cover of less than 20 per cent.
- 4 tree grassland
Grassland with scattered or grouped trees, always conspicuous, but having a canopy cover of less than 20 %.
- 5 bush tree grassland
Same as 3 and 4, but trees and shrubs equally represented
- 6 bushland
Land supporting an assembly of trees and shrubs, often dominated by plants of shrubby habit, and a total canopy cover of more than 20 per cent.
- 7 woodland
Land supporting a stand of trees, up to 20 m in height, and a canopy cover of more than 20 per cent.
- 8 bush woodland
Same as 6 and 7, but trees and shrubs equally represented
- 9 forest
Land covered by a closed stand of trees of one or more storeys, with an interlaced upper canopy.

2. Cultivation:

- 0 no cultivation
- 1 village
- 2 fallow
- 3 unspecified cultivation
- 4 millet (Arabic: Dukhn)
- 5 sorghum (Arabic: Dura)
- 6 sesame (Arabic: Simsim)
- 7 water melon
- 8 ground nut (Arabic: Fuul)
- 9 Acacia senegal (Arabic: Hashab)
- 10 cotton

3. Key species:

- 0 no key species
- 1 *Calotropis procera* (Arabic: Usher)
- 2 *Leptadenia pyrotechnica* (Arabic: Marakh)
- 3 *Cacia Acutifalia* (Arabic: Senesene)
- 4 *Boscia senegalensis*

4. Canopy and field cover:

A qualitative scale of canopy and field cover was used. Attempts were made to calibrate this to real percentage values. It was found that the qualitative estimation is very consistent but it is difficult to calibrate it to percentage values. The estimation accuracy is highest in the low range, 0 - 30 per cent cover, and the estimations become coarser the denser the cover. The following qualitative scales were used:

- 0 no cover
- 1 low cover

- 2
- 3
- 4
- 5
- 6
- 7 complete cover

5. Grazing intensity:

The grazing intensity was ranked into 6 classes. Cultivated fields with stalks left after harvest have been considered as areas of no grazing, while fields with stalks partly or completely removed have been considered as grazed.

- 0 no grazing
- 1 low grazing intensity
- 3
- 5
- 7
- 9 completely over-grazed

6. Macro relief:

- 1 completely flat landscape
- 3
- 5
- 7
- 9 very mountaineous

7. Micro relief:

- 0 no natural ground
- 1 smooth surface
- 3
- 5
- 9 very rough surface

8. Soil colour:

The colour of the soil was estimated by comparison with a simplified Munsell colour scale. It was found that it was possible to make rather fine colour estimations from the car.

9. Soil erosion:

Soil erosion was estimated according to the presence or not of erosion indicators. The type of erosion and a qualitative estimation of the intensity of erosion was done.

An erosion indicator allowing quantification of soil erosion rate is shown in Fig. 3.5. The root of a bush in sandy soil has been exposed by wind erosion. Between 20 and 25 cm of soil has been removed.

Types of erosion:



Fig. 3.5. A wind erosion indicator. The roots of a bush have been exposed by removal of 20 - 25 cm of soil, north of Hamrat El Wiz, February 1982.

- 0 no erosion indicators
- 1 nebkas
- 2 dunes
- 3 ripples
- 4 exposed roots
- 5 sheet erosion
- 6 rill erosion
- 7 gully erosion
- 8 wadi area
- 9 exposed crust
- 10 deflation area
- 11 tree mounts

Intensity of erosion:

- 0 no erosion indicators
- 1 low intensity
- 3
- 5
- 7
- 9 high intensity of erosion

10. Soil type:

- 1 sand
- 2 silt
- 3 clay

- 4 gravel and coarser
- 5 bedrock
- 6 pediment surfaces
- 7 gardud soil

11. Geographical position:

Average compass readings were taken twice per sampling point. Processing of the direction data and distance data by dead reckoning generated geographical position of each sampling point.

4. STATISTICAL DESCRIPTION OF THE LANDSCAPE

The result of a field sampling is a large number of data points containing nonparametric data on 12 environmental parameters, geographical position excluded. Data on stratum belonging is important to add, either during sampling or afterwards. A number of other parameters, taken from thematic maps and areal statistics can be added afterwards, see Chapter 5.

Simple descriptive statistics can be used for thematic description of the landscape. Comparison by sample results from different occasions can be used to study changes in the landscape. A number of tables describing some of the most important features of the study area in February March 1982 are presented below, Tab. III.3. The sampling route and the stratification is shown in Fig. 3.6.

Tab. III.3. Tabulation of sampled environmental variables

VEGETATION	1	2	3	4	6	TOT	CANOPY COVER	1	2	3	4	6	TOT
No. nat. veg.	27.6 13.6	10.1 9.4	7.8 5.9	1.2 25.0	5.0 2.9	11.2 11.2	No cover	17.1 30.6	6.5 24.9	2.3 22.8	0.3 25.0	1.6 22.9	27.7 27.7
Desert	2.0 3.5	1.5 5.7	0.4 4.0	-- --	1.5 21.4	5.3 5.3	1 = Sparse cover	19.6 35.2	7.8 29.8	2.4 23.8	-- --	4.0 58.6	33.8 33.8
Grassland	27.2 48.8	11.3 43.4	4.4 44.6	-- --	3.2 45.7	46.1 46.1	2	8.2 14.6	4.4 17.0	0.8 7.9	-- --	-- --	13.4 13.4
Bush grassland	14.2 25.4	6.2 23.8	1.2 11.9	-- --	1.2 17.1	22.8 22.8	3	9.1 16.3	4.7 18.1	3.4 33.7	-- --	1.3 18.6	18.4 18.4
Tree grassland	0.3 .5	1.5 5.7	0.9 8.9	-- --	0.2 2.9	2.9 2.9	4	1.5 2.7	2.3 8.7	1.1 11.9	0.8 66.7	-- --	5.7 5.7
Bushland	1.1 1.9	1.3 4.9	2.5 24.8	0.3 25.0	0.5 7.1	5.6 5.6	5 = very dense cover	0.4 0.7	0.4 1.5	-- --	0.1 8.3	-- --	0.9 0.9
Woodland	2.7 4.8	1.4 5.3	-- --	0.5 41.7	0.1 1.4	4.6 4.6	FIELD COVER	1	2	3	4	6	TOT
Forest	0.8 1.4	0.5 1.9	-- --	0.1 8.3	0.1 1.4	1.5 1.5	No cover	24.0 42.9	9.8 37.4	2.5 24.8	0.8 66.7	6.9 100.0	43.9 43.9
CULTIVATION	1	2	3	4	6	TOT	1 = Sparse cover	18.3 32.9	6.4 24.5	5.9 59.4	0.3 25.0	-- --	31.0 31.0
No cultivation	24.9 44.5	18.7 71.7	8.3 83.2	1.0 83.3	6.7 97.1	59.6 59.6	2	6.9 12.4	4.5 17.4	1.2 11.9	0.1 8.3	-- --	12.7 12.7
Fallow	3.4 6.0	0.9 3.4	0.2 1.2	-- --	-- --	4.4 4.4	3	3.9 6.9	2.2 8.3	0.2 2.0	-- --	-- --	6.2 6.2
Unspec. cultivation	0.3 0.5	-- --	0.2 2.0	-- --	-- --	0.5 0.5	4	1.7 3.0	1.7 6.4	-- --	-- --	-- --	3.4 3.4
Millet	12.6 22.6	3.4 12.8	0.6 5.9	-- --	0.2 2.9	16.8 16.8	5 = very dense cover	1.1 1.9	1.6 6.0	0.2 2.0	-- --	-- --	2.9 2.9
Sorghum	0.9 1.8	-- --	0.2 2.0	-- --	-- --	1.2 1.2							
Sesame	6.7 12.0	0.2 0.8	0.4 4.0	-- --	-- --	7.3 7.3							
Acacia senegal	6.9 12.4	3.0 11.3	0.1 1.0	0.2 16.7	-- --	10.2 10.2							

KEY SPECIES	1	2	3	4	6	TOT
No key species	27.6 49.5	10.1 38.5	7.8 78.2	1.2 100.0	5.0 72.9	51.7 51.7
Calotropis procera	6.3 11.3	0.3 1.1	-- --	-- --	-- --	6.6 6.6
Leptadenia pyrotechnica	15.8 28.3	15.5 59.3	-- --	-- --	0.7 10.0	32.0 32.0
Boscia senegalensis	5.9 10.6	-- --	2.2 21.8	-- --	1.1 15.7	9.2 9.2
GRAZING INTENSITY	1	2	3	4	6	TOT
0 = No grazing	10.1 18.0	3.2 12.1	1.0 9.9	0.3 25.0	0.8 11.4	15.3 15.3
1 = Low intensity	1.5 2.7	2.7 10.2	0.1 1.0	-- --	-- --	4.2 4.2
2	3.6 6.4	1.8 6.8	0.3 3.0	-- --	-- --	5.6 5.6
3	4.2 7.6	1.3 4.9	0.8 7.9	-- --	-- --	6.3 6.3
4	10.4 18.6	3.2 12.1	3.7 36.6	0.3 25.0	-- --	17.5 17.5
5 = overgrazed	26.1 46.8	14.1 54.0	4.1 41.6	0.6 50.0	6.1 88.6	51.1 51.1
EROSION TYPE	1	2	3	4	6	TOT
No erosion marks	30.6 54.8	15.5 59.3	4.7 47.5	0.8 66.7	1.2 17.1	53.0 53.0
Nebkas	5.3 9.5	4.2 16.2	0.1 1.0	-- --	4.3 62.9	14.0 14.0
Dunes and ripples	1.5 2.7	3.6 13.6	-- --	-- --	0.1 1.4	5.1 5.1
Sheet and rill erosion	-- --	0.1 0.4	0.8 7.9	-- --	0.1 1.4	1.0 1.0
Wadi areas	0.4 0.7	-- --	0.1 1.0	0.4 33.3	0.3 4.3	1.2 1.2
Deflation surfaces	8.3 14.8	2.8 10.6	3.8 37.6	-- --	0.9 12.9	15.7 15.7
Tree mounts	9.8 17.5	-- --	0.5 5.0	-- --	-- --	10.3 10.3
EROSION INTENSITY	1	2	3	4	6	TOT
0 = No erosion marks	30.5 54.8	15.5 59.3	4.8 48.5	1.2 100.0	1.0 14.3	53.0 53.0
Low intensity	6.6 11.8	0.5 1.9	1.2 11.9	-- --	0.1 1.4	8.4 8.4
Moderate intensity	11.1 19.8	7.4 28.3	3.0 30.0	-- --	4.2 61.4	25.6 25.6
High intensity	7.6 13.6	2.8 10.6	1.0 9.9	-- --	1.6 22.8	12.9 12.9
	1	2	3	4	6	TOT
TOTAL PERCENTAGES:	55.8	26.1	10.0	1.2	6.9	100.0 (N=1014)

MACRO RELIEF	1	2	3	4	6	TOT
1 = Completely flat	2.5 4.4	1.2 4.5	0.3 3.0	0.3 25.0	-- --	4.2 4.2
2	38.8 69.4	21.0 80.0	8.0 80.2	0.6 50.2	6.7 97.1	75.0 75.0
3	14.1 25.3	4.0 15.1	2.5 14.9	0.2 25.0	-- 2.9	20.8 20.8
4 = Very mounteanous	0.5 0.9	0.1 0.4	0.2 2.0	-- --	-- --	0.8 0.8
MICRO RELIEF	1	2	3	4	6	TOT
1 = No natural ground	2.5 4.4	1.4 5.3	0.3 3.0	0.3 25.0	0.3 4.3	4.7 4.7
2 = Smooth surface	51.9 92.9	23.8 90.9	8.7 87.1	0.8 66.7	4.8 70.0	90.0 89.9
3 = Rough surface	1.5 2.7	1.0 3.8	1.0 9.9	0.1 8.3	1.8 25.7	5.3 5.3
SOIL COLOUR	1	2	3	4	6	TOT
713	0.2 0.4	0.4 1.5	1.5 14.9	-- --	-- --	2.1 2.1
715	0.2 0.4	-- --	0.2 2.0	-- --	-- --	0.4 0.4
751	0.3 0.5	1.0 3.8	-- --	-- --	-- --	1.3 1.3
753	0.6 1.1	-- --	-- --	-- --	-- --	0.6 0.6
791	1.1 1.9	-- --	-- --	-- --	-- --	1.1 1.1
1511	3.9 6.9	3.4 12.8	0.1 1.0	-- --	1.5 21.4	8.9 8.9
1513	2.0 3.5	2.3 8.7	2.2 21.8	0.2 16.7	-- --	6.6 6.6
1515	1.0 1.8	-- --	1.1 10.9	0.6 50.0	-- --	2.7 2.7
1551	33.1 59.4	18.2 69.8	2.0 19.8	0.1 8.3	5.2 75.7	58.7 58.7
1553	11.4 20.5	0.9 3.4	2.4 23.8	0.2 16.7	0.1 1.4	15.0 15.0
SOIL TYPE	1	2	3	4	6	TOT
Sand	46.9 84.1	24.8 94.7	1.8 17.8	0.2 16.7	2.8 40.0	76.4 76.4
Silt	3.2 5.7	0.2 0.8	5.0 50.5	-- --	3.1 44.3	11.4 11.4
Clay	2.7 4.8	-- --	0.7 6.9	0.7 58.3	0.7 10.0	4.7 4.7
Gravel and coarser	0.7 1.2	-- --	0.6 5.9	-- --	0.3 4.3	1.6 1.6
Bedrock	-- --	-- --	1.4 13.9	-- --	-- --	1.4 1.4

The upper figures denote total percentages and the lower ones, column percentages.

The different strata are:

1 = cultivated Qoz

2 = grazed Qoz

3 = Gardud soils

4 = Wadi areas

6 = desert soils

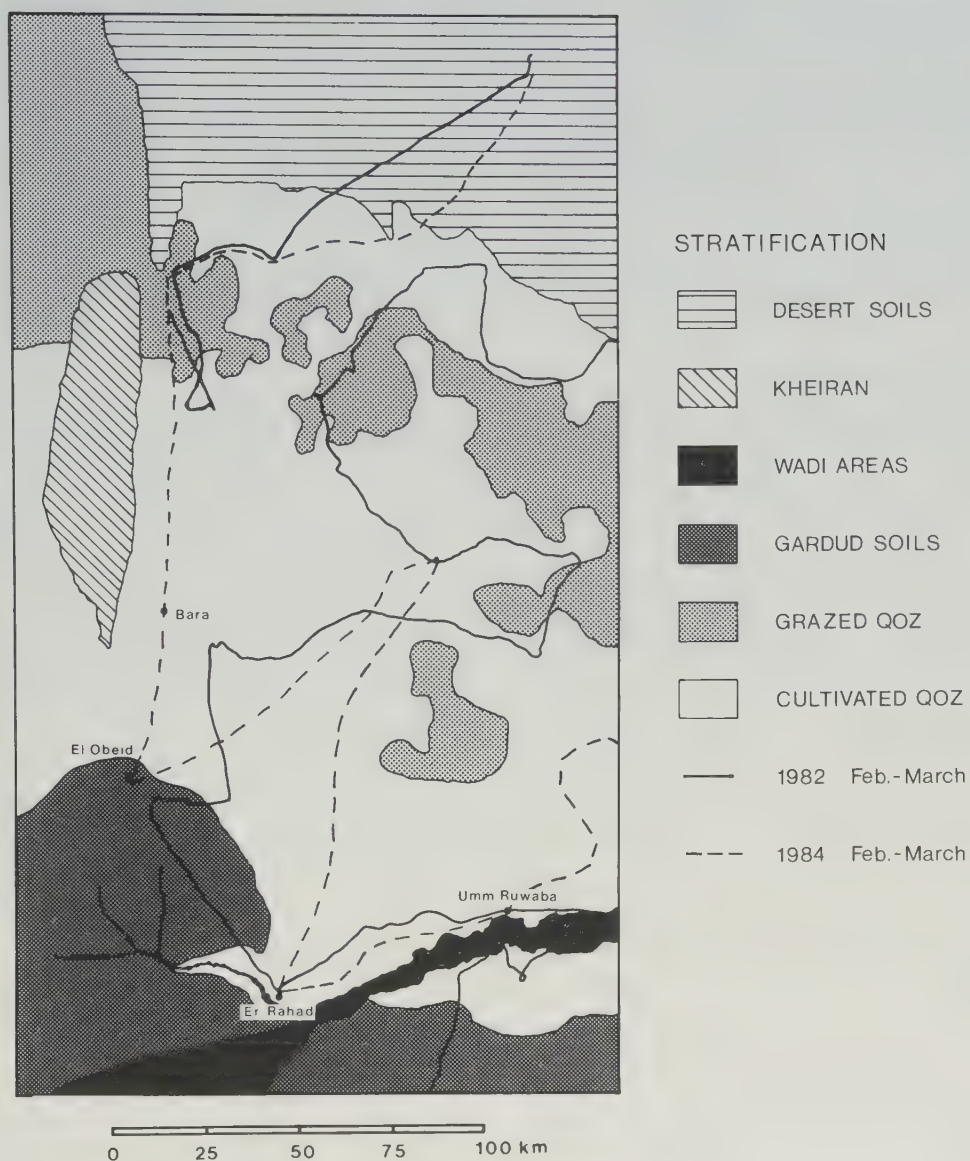


Fig. 3.6. The stratification used for field data collection in 1982 and 1984. Solid line shows the route in 1982 and dashed line the route in 1984.

four

Remote Sensing

1. INTRODUCTION

Remote sensing has been a field of research for several decades so far, and digital remote sensing for at least one decade. Methods for analysis (e.g. geometric correction, classification and image enhancement) of digital data have continuously been developed and elaborated. Satellite remote sensing has been considered to have a unique potential for inventories of natural resources and operational environmental monitoring. However, in spite of this the true operational applications of remote sensing have been few. A large number of pilot and feasibility studies have been carried out in order to demonstrate the potential of the technique in several fields, e.g. vegetation, land use and forest inventories.

In spite of the rapid development of remote sensing techniques concerning data quality, as well as hardware and software for the analysis, the results have often been fairly disappointing. It has not, for example, been possible to map more than 5 - 8 land cover classes with acceptable degree of accuracy, (Hellden 1979, 1980 and Hellden & Stern 1980). Spectral signatures have not proven to be accurate and unique enough to be used as a base for automatic classification. The cartographic product that is mostly the output from a remote sensing study have seldom met the requirements of a modern thematic map regarding basic map information, e.g. geographical names, roads, administrative boundaries as well as thematic accuracy.

As a conclusion I maintain that satellite remote sensing alone, without the availability and possibilities of superimposing and using relevant ancillary information, is often insufficient to yield reliable result concerning inventories of natural resources and environmental monitoring. However, I consider remote sensing to have a very high potential for contributing to modern geographical, physical as well as human, research. The remedies to many of the weaknesses of remote sensing is to combine it with ancillary information in a geographical information system (GIS). Three US geographers expressed it very strongly as follows: "When allied with the traditional cornerstone of geography, i.e. cartography, in its new digital raiment, the two techniques can go far beyond being mere technologies. We predict they could change our perceptions, our methods

of data analysis, our models and our paradigms" (Estes, Jensen & Simonett 1980).

Much of the modern development in remote sensing aims at integrating data from different sources with remotely sensed data in order to improve the quality of the resulting thematic maps. The improvements are of two kinds:

1. Improved classification accuracy. This can be achieved by integration of e.g. digital soil maps (Olsson 1984d) or elevation data for improved classification result of mountainous forests (Strahler et. al. 1980 and Richards et. al. 1982).
2. Improved utility of the resulting maps. The cartographic quality may be improved by overlays of e.g. roads, administrative boundaries and geographical names (e.g. Graetz et. al. 1982, 1984).

Data which are not in raster format, e.g. areal statistics, are difficult to treat in a conventional remote sensing system. Different methods of interpolation can be used to transform sampled continuous data, e.g. meteorological data, into a regular grid net. Non-continuous data (in a spatial sense), e.g. village population and capacity of a well, can not be treated in this way. The data is confined to a certain point or valid only for a certain region, but exert an influence on the surroundings. Spatial models can, however, serve as a tool for representing this kind of data, and to simulate the spatial influences, in a regular grid net.

The geographical information system approach and spatial models will be treated in the subsequent chapters.

Remote sensing has played a very important role in this thesis, from the definition of study area, development of field methods to the analysis and presentation of data. The different aims of the remote sensing work have been:

1. The study of temporal variations in vegetation type, biomass and albedo through multitemporal image analysis. The original aim was to cover the study area several times from 1972 up to the present time. Unfortunately, the latest available Landsat image is from 1979. The dates chosen for analyses were January 1, 1973, January 6, 1979, March 19, 1979 and September 24, 1979.
2. The study of settlements, location and size, according to methods developed by Stern (1982, 1984, 1985).
3. Statistical analyses of relationships between Landsat data and ancillary information. This was done in an attempt to investigate the relationships between different environmental variables, and also the impact of these variables on the Landsat imagery.

The approach has been to treat remote sensing, not as a discipline in itself, but only one method of geographical research, although a very important one, and an integrated part of a geographical information system.

Up to autumn 1979, the study area was very well covered by Landsat data from the beginning of the Landsat program in 1972. From 1980 and onwards, there have been no, or very few acquisitions of Landsat data over the region. Therefore, some of the original aims of this thesis regarding the remote sensing part have been changed. It has been impossible to include any field observations taken simultaneously with a satellite passage. This means that absolute calibrations of satellite data to measured ground conditions have not been carried out. The work has rather been concentrated on studies of relative changes in images from different times. Ancillary data and field work from more recent occasions have been used in order better to be able to interpret the data.

2. PREPROCESSING

2.1 Radiometric Calibration

Multitemporal analysis of Landsat data requires proper calibration of the different images in order to make them comparable. There are principally two different influences that affect the image data, satellite or sensor characteristics and atmospheric conditions at the time of recording.

Sensor characteristics have varied between the different Landsat versions as well as gradually over time for each satellite. The multispectral scanner data are continuously calibrated on board. Calibration data necessary for radiometric correction of the images are described in e.g. USGS (1979). A compilation of calibration data for different Landsat satellites was presented by Robinove et. al. (1981). Information necessary for correction of Landsat 1 - 3 is presented in Tab.IV.1.

One way of making data from different dates comparable is to transform the digital grey levels (DGL) to absolute radiance or reflectivity values, expressed in (mW/cm² sr). A correction for additive atmospheric scattering is usually also included. This transformation is done through the formula presented below (Robinove et. al. 1981):

$$R_i = (B_i - B_{min}) / (Gain * \sin a)$$

where: R_i = Reflectivity (mW/cm² sr) in band i

B_i = Digital Grey Level in band i

B_{min} = Minimum DGL in band i (in full uncorrected Landsat scene).

G = Gain, in DGL per unit radiance (Tab.IV.1)

a = Solar elevation angle (as noted in Landsat image annotation).

Tab. IV.1. Landsats 1, 2 & 3 detector response, gain and offset data used for radiometric calibration of MSS data.

MSS BAND	WAVELENGTH (μM)	MINIMUM		MAXIMUM		GAIN	OFFSET
		BRIGHTNESS VALUE (DIGITAL COUNT)	RADIANCE (mW/cm ² sr)	BRIGHTNESS VALUE DIGITAL COUNT)	RADIANCE (mW/cm ² sr)		
Landsat 1							
4	0.5-0.6	0	0	127	2.48	51.21	0
5	0.6-0.7	0	0	127	2.00	63.51	0
6	0.7-0.8	0	0	127	1.76	72.16	0
7	0.8-1.1	0	0	63	4.00	15.75	0
Landsat 2 (22 January 1975 to 16 July 1975)							
4	0.5-0.6	0	0.10	127	2.10	63.50	0.10
5	0.6-0.7	0	0.07	127	1.56	85.23	0.07
6	0.7-0.8	0	0.07	127	1.40	95.49	0.07
7	0.8-1.1	0	0.14	63	4.15	15.71	0.14
Landsat 2 (after 16 July 1975)							
4	0.5-0.6	0	0.08	127	2.63	49.80	0.08
5	0.6-0.7	0	0.06	127	1.76	74.71	0.06
6	0.7-0.8	0	0.06	127	1.52	86.99	0.05
7	0.8-1.1	0	0.11	63	3.91	16.59	0.11
Landsat 3 (5 March 1978 to 31 May 1978)							
4	0.5-0.6	0	0.04	127	2.20	58.80	0.04
5	0.6-0.7	0	0.03	127	1.75	73.84	0.03
6	0.7-0.8	0	0.03	127	1.45	89.44	0.03
7	0.8-1.1	0	0.03	63	4.41	14.38	0.03
Landsat 3 (after 31 May 1978)							
4	0.5-0.6	0	0.04	127	2.59	49.80	0.04
5	0.6-0.7	0	0.03	127	1.79	72.16	0.03
6	0.7-0.8	0	0.03	127	1.49	86.99	0.03
7	0.8-1.1	0	0.03	63	3.83	16.53	0.03

Source: Robinove et. al. (1981)

The transformation above is, however, only valid under four assumptions.

1. The terrain surface is a Lambertian (diffuse) reflector. This assumption is a good approximation of the reflectance characteristics of the solid part of the Earth's surface (Hugli & Frei 1983). However, for several types of material this assumption may be violated. Loose sand, for example, is a typical forward scatter (Middleton & Mungall 1972).
2. The average terrain slope is zero. This assumption may be relevant in the study area.
3. The atmospheric scattering is only additive. This assumption has been discussed by Hellden (1984), where a special way of scaling of the data is supposed to minimize all external wave length dependent noise. This approach will be described below.
4. The sun angle contribution to the scene brightness is uniform over the entire scene.

In order to minimize external influences on the Landsat images

further a second scaling of the data was carried out by Hellden (1984). This scaling assumes that the ground conditions corresponding to the highest and the lowest pixel values, do not change reflectance properties over time. In the scene analysed, the darkest pixels were found in complete shadow (Jebel ed Dair) and the brightest pixels in bare white sand (sand dunes in the Kheiran area). The scaling algorithm is shown below:

- (1) $B_{hist} = B_i - B_{min}$
- (2) $B_{new} = B_{hist} * (255 / B_{max})$

Where B_{hist} = new pixel value after histogram subtraction

B_i = pixel value in raw data

B_{min} = value of the darkest pixel in the scene

B_{max} = value of the brightest pixel in the scene after the histogram subtraction

B_{new} = the resulting scaled pixel value (0 - 255)

If the two assumptions are not violated, this scaling should eliminate all external wavelength-dependent noise (Hellden 1984).

For the image analysis in this thesis I have used the first approach to radiometric calibration for the albedo and principal components transformations, and the second approach for the biomass transformations.

2.2 Geometrical Correction

Since the analyses to a large extent involves multi-temporal analysis of images and the integration of ancillary information, the geometrical precision is important. As mentioned before, the maps of the region are of very low quality, regarding thematic content and accuracy as well as geometrical precision.

The topographical maps over the study area, to the scale of 1:250 000, were dated 1936, Sudan Survey Department, but the note in Fig. 4.1 indicates that the survey is much older.

NOTE: The topography is based on Col Pearson's latitude and telegraphic longitude of Er Renk (1908) and Commander Whitehouse's Eastern Jebels (Kordofan) Triangulation (1933). The river from Er Renk northwards is from Egyptian Irrigation surveys and southwards from old surveys in 1902 with additions & corrections by Major O'Sullivan & Capt. Coningham. Other detail is from sketches by Cpts. Vickery and Cox and Messrs. Hancock, Elles and Kingston

(Province Boundaries and Railways Corrected 1975)

Fig. 4.1. A note on the topographical map sheet NC 35 H, published by the Sudan Survey Department, 1977.

Geometrical correction of digital images is carried out through resampling, using different degrees of polynomial transformation functions. When the geometrical accuracy of the map is considered to be less than the accuracy of the satellite image, it is better to use only a few ground control points (3 - 4), and a low degree polynomial transformation. Then the image can be rotated without changing the geometry of it. The use of many control points and a high degree (2 or 3) polynomial transformation will change the internal geometry of the image substantially.

The geometric correction of the images and ancillary information layers has been carried out in the following way.

1. The Landsat image from March 19, 1979, has been taken as a geometrical baseline, with a pixel size of 50 m. All other images have been resampled, "image to image" to this. The resampling algorithm was a third degree polynomial and cubic convolution, based on approximately 30 ground control points. The residuals at the ground control points did not exceed 1 pixel.
2. All images have then been resampled by cubic convolution (digitized maps and thematic images by nearest neighbour), to the topographical map (1:250 000). The geometrical precision was low. Only a few ground control points could accurately be found. The map was found to contain severe errors even in points indicated as triangulation points. The maximum residual was estimated to be 400 m.
3. In order to reduce the data volume and to facilitate the work with spatial models the pixel size was reduced to 250 m by resampling.

3. IMAGE ANALYSIS

The digital image from e.g. Landsat consists of an enormous amount of information. The information can be divided into three types of image elements, spectral, textural and contextual information, (Haralick & Shanmugam 1974). Spectral information relates to the band-to-band variations of a single pixel in a multispectral image. Textural information relates to the spatial distribution of pixel values. Texture is usually measured in a local neighborhood of a pixel. Context information relates to an a priori knowledge of the surrounding of a pixel or region. The latter two kinds of information are often denoted as spatial information.

The recognition of spatial information as very important in image classification of remotely sensed data is not new. One important difference between manual interpretation of images and computerized analysis of digital data is the treatment of spatial information. The manual interpretation of images is to a large extent dependent on textural and context information,

i.e. the interpreter does not only consider the actual point to be classified but takes also the surrounding into consideration in the classification procedure. Conventional computer classification on the other hand, is entirely based on the spectral information in the pixel to be classified.

3.1 Spectral Information

3.1.1 Multispectral Classification

Previous studies in arid and semi-arid regions have shown that the number of land cover classes that can be mapped accurately by supervised multi-spectral classification is rather limited. Hellden (1980) and Hellden & Stern (1980) showed that only 5 - 8 classes could be mapped with acceptable degree of accuracy. Multispectral classification (supervised as well as unsupervised) of semi-arid rangelands in Australia was rejected by Graetz et.al (1982) because "the underlying assumption of both these approaches, i.e. informational classes were readily separable in spectral data space, was most unlikely to hold in the rangelands". Coiner (1980) also rejected a classification in a study on vegetation cover in Mali. "Conventional methods (i.e. multispectral classification) were felt to incorporate unnecessary local variability (noise) that submerged information relevant to development of regional vegetation change and status mapping" (ibid.)

Although multi-spectral classification has several weaknesses and is much criticized, it is in many cases desirable and necessary to use the technique. There exist several means of improving multi-spectral classification.

The expected areal distribution of classes in a classification can be used as prior probabilities to improve the ML classification result. Commonly these prior probabilities are assumed to be equal (0.5 in the two-class case). Separate prior probabilities for each class can be used in maximum likelihood (ML) classification. More accurate classification should result if the prior probabilities could be accurately estimated from external data, e.g. ground surveys (Schowengerdt 1983). Bauer et. al. (1979) used separate prior probabilities in order to improve the accuracy of classification of agricultural crops. The prior probabilities were estimated from agricultural statistics in the previous years. Théry concluded however that "... while the theoretical basis for the use of prior probability information in the classification discriminant function is sound, in practice it may not substantially change the results". The overall classification result in their study of corn and soybeans increased by only 2.3 %. On the other hand, Strahler (1980) states "... the inclusion of collateral data as prior probabilities to ML classification offers a simple and effective way of combining collateral and remotely sensed data."

Another way of improving the classification result is to use

ancillary data as "logical channels" (Strahler et. al. 1978) or non-spectral bands. The non-spectral bands can consist of e.g. elevation data (DEM), digitized soil map or interpolated climatic data. Several ways of incorporating the non-spectral information into the classification exist. Richards et. al. (1982) used the technique of relaxation to combine the result from a conventional ML classification of multi-spectral Skylab data with DEM data. Strahler (1980) used similar techniques. The calculated probabilities (the penultimate step, before the final class labeling, in ML classification) were corrected for prior probabilities derived from non-spectral bands.

Some authors (e.g. Tom & Miller 1980) have used non-spectral bands as extra features in conventional ML classifications. The drawbacks with this approach are among others (Richards et. al. 1982):

1. The ancillary data must be normally distributed, which means that categorical types of data, e.g. digitized soil map, can not be used.
2. The relative scaling of the spectral and the ancillary data may be important.
3. More training data may be necessary to give reliable covariance estimates
4. There is a quadratic increase in classification cost with the addition of features when using Gaussian ML classification.

A simple and efficient way of using categorical types of data as nonspectral bands is to carry out conventional ML classification under mask. Areas can either be excluded by the use of thematic bands or different sets of training statistics can be used within different themes.

Textural information can be used in classification, either as a nonspectral band or that some way of spatial operations be included in the classification algorithm. Strahler et. al. (1978 & 1979) used the standard deviation from a 3 x 3 filter as a non-spectral band. This was reported to increase the classification of tree species by 27 % compared with conventional ML classification. Lid Hjort & Mohn (1984) compared several classification algorithms, among them an autocorrelation model that proved to be superior to the other ones. The assumption here is that there exists a high degree of spatial autocorrelation in the image data, i.e. adjacent pixels are more likely to belong to the same class than pixels at greater distances from each other.

3.1.2 Principal Component Analysis (PCA)

Principal component analysis (or Karhunen-Loeve transformation) is a data transformation technique commonly applied in multiva-

riate statistical analysis. For a description of the technique, please refer to e.g. Daultrey (1976) or Johnston (1980). The aim of principal components analysis in remote sensing is to remove redundancy in the multi-spectral image by rotating the axes into principal components which maximise variance in the data, see Fig. 4.2. The first component will contain the largest possible amount of the total variance, the second component will contain the largest possible amount of the remaining variance, and so on.

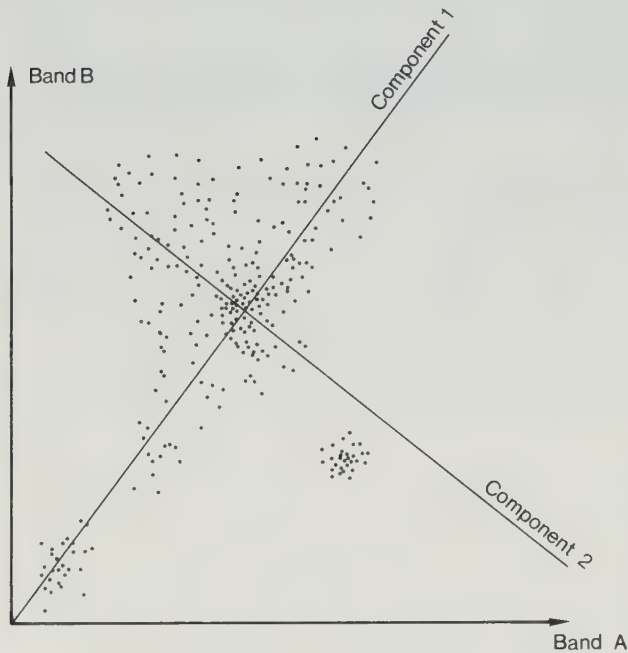


Fig. 4.2. The principle of a principal component transformation in two dimensions.

It has been shown several times that the individual MSS bands are highly correlated. According to Schowengerdt (1983), this correlation arises from:

1. Natural spectral correlation. This correlation is caused by e.g. the low reflectance of vegetation in MSS 4 and MSS 5, and the high reflectance in MSS 6 and MSS 7.
2. Topographic influence on the image.
3. Overlap in spectral sensitivity between adjacent spectral bands.

In Tab. IV.2. the correlation matrices from the training area used for PC transformation are presented.

Due to the high correlation between MSS bands, component 1 will contain very much of the total variation, typically between 85 and 95 %. The first two components will mostly contain more

Tab. IV.2. Correlation matrices from the training areas used for principal components transformation, together with the loading of each component.

	MSS 4	MSS 5	MSS 6	MSS 7		% variance
January 1 1973						
MSS 4	1.00				Comp. 1	94.5
MSS 5	0.81	1.00			Comp. 2	2.8
MSS 6	0.76	0.96	1.00		Comp. 3	1.8
MSS 7	0.73	0.93	0.94	1.00	Comp. 4	1.0
January 6 1979						
MSS 4	1.00				Comp. 1	94.4
MSS 5	0.77	1.00			Comp. 2	3.4
MSS 6	0.70	0.95	1.00		Comp. 3	1.3
MSS 7	0.64	0.91	0.96	1.00	Comp. 4	0.8
March 19 1979						
MSS 4	1.00				Comp. 1	93.1
MSS 5	0.77	1.00			Comp. 2	4.5
MSS 6	0.74	0.96	1.00		Comp. 3	1.7
MSS 7	0.66	0.83	0.84	1.00	Comp. 4	0.8
September 24 1979						
MSS 4	1.00				Comp. 1	89.7
MSS 5	0.93	1.00			Comp. 2	6.7
MSS 6	0.78	0.87	1.00		Comp. 3	2.8
MSS 7	0.74	0.82	0.90	1.00	Comp. 4	0.7

than 95 % of the variation. The intrinsic dimensionality (Landgrebe 1978) can therefore be set to two. In multi-temporal analyses, principal component transformation can be a useful tool to reduce the number of wavelength bands. The first three components of the four Landsat scenes analysed are presented in Figs. 4.3 - 4.14.

The two-dimensional perpendicular vegetation index (PVI) and soil line index (SLI) developed by Wiegand and Richardson (Richardson & Wiegand 1977 and Wiegand & Richardson 1982) and the four-dimensional tasseled cap transformation of Kauth & Thomas (1976) (see section 3.1.4), are transformations similar to principal components transformation. The main difference is that these transformations are based on certain a priori knowledge of the spectral behaviour of soil and vegetation. Principal components transformation does not include any a priori knowledge of spectral properties, but is only aimed at maximizing the variance in each component.

Apart from data reduction, PCA can be of value in enhancing regions of localized change in multi-dimensional images (Byrne & Crapper 1979, Byrne et. al. 1980 and Richards 1984).

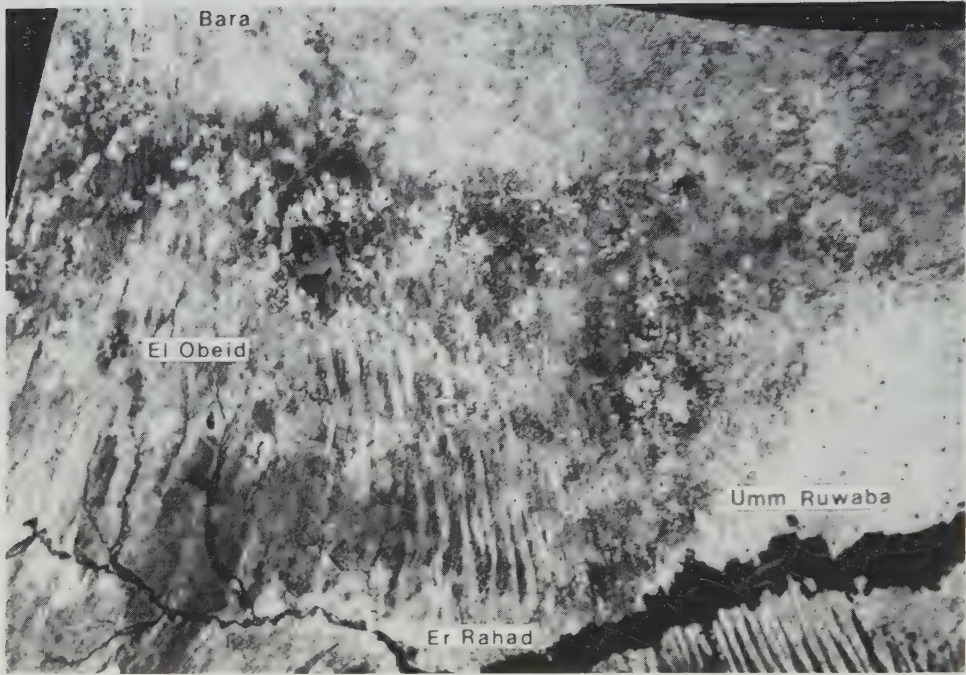


Fig. 4.3. Principal component 1 of the January 1973 scene, containing 94.5 % of the variation.

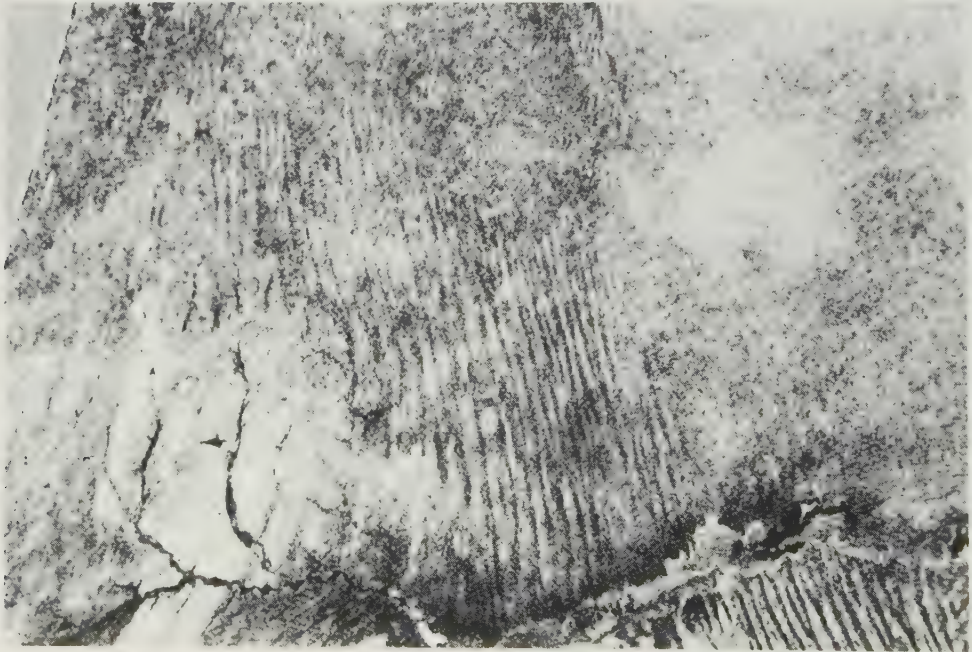


Fig. 4.4. Principal component 2 of the January 1973 scene, containing 2.8 % of the variation. Note the enhancement of the geomorphological pattern of the dune systems.

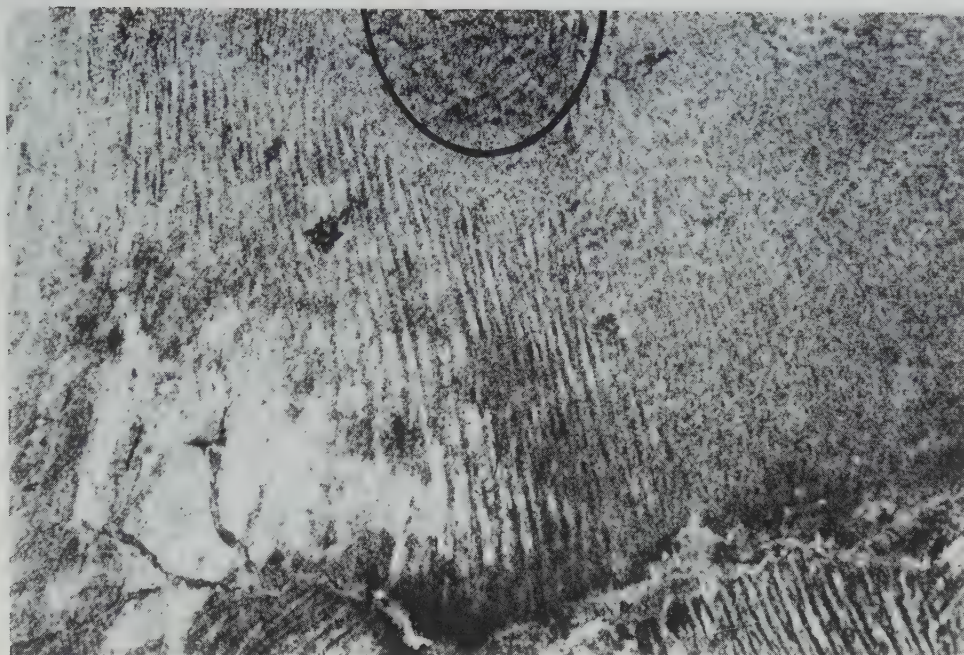


Fig. 4.5. Principal component 3 of the January 1973 scene, containing 1.8 % of the variation. The image contains to a large extent noise, but some of the geomorphological features of the region have been enhanced, e.g. the difference between the different soil associations east of Bara. The line indicates the boundary between longitudinal dunes and transversal dunes.

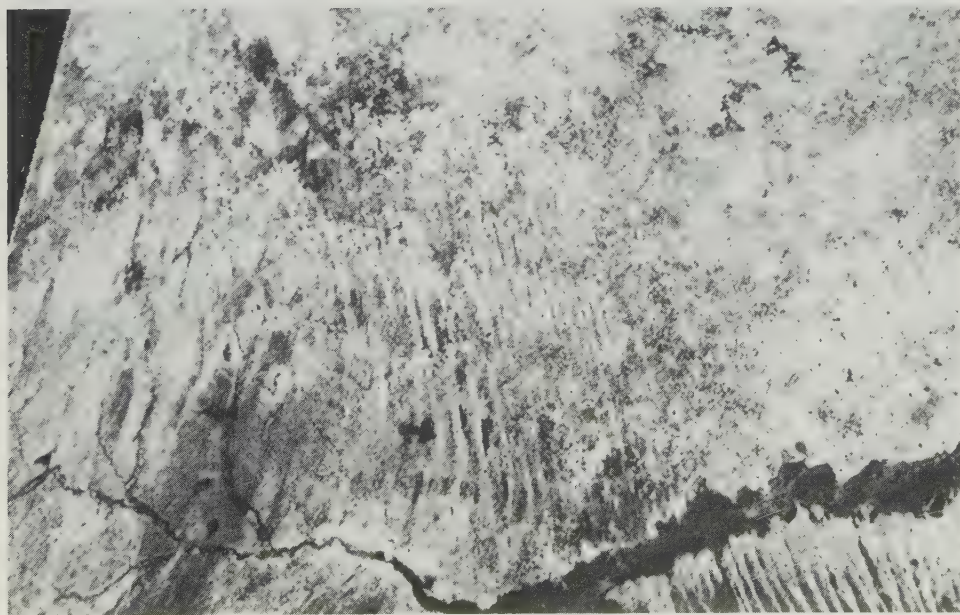


Fig. 4.6. Principal component 1 of the January 1979 scene, containing 94.4 % of the variation.

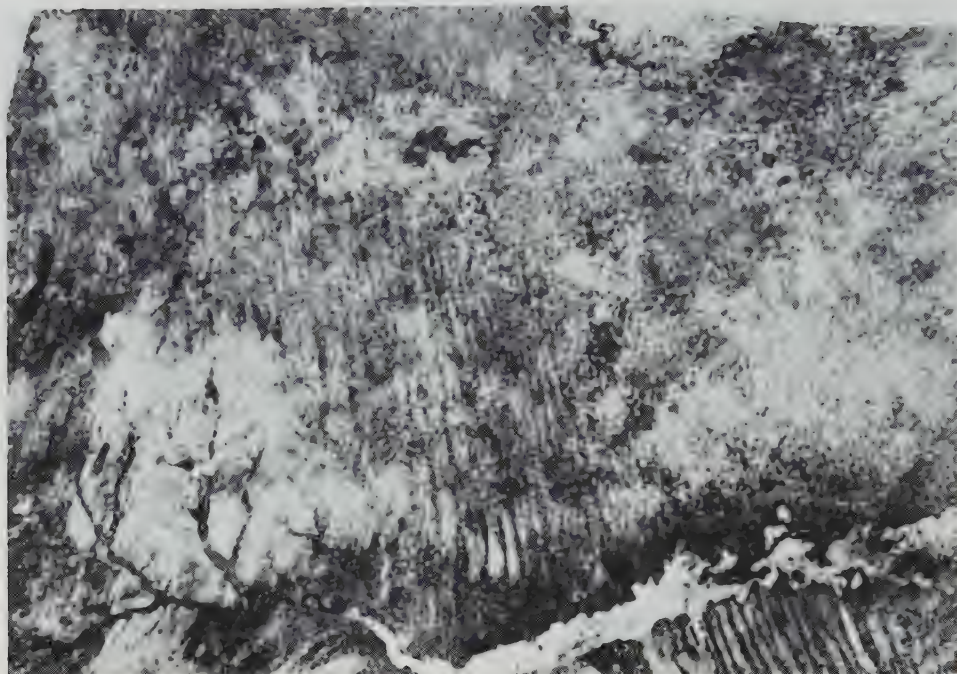


Fig. 4.7. Principal component 2 of the January 1979 scene, containing 3.4 of the variation.

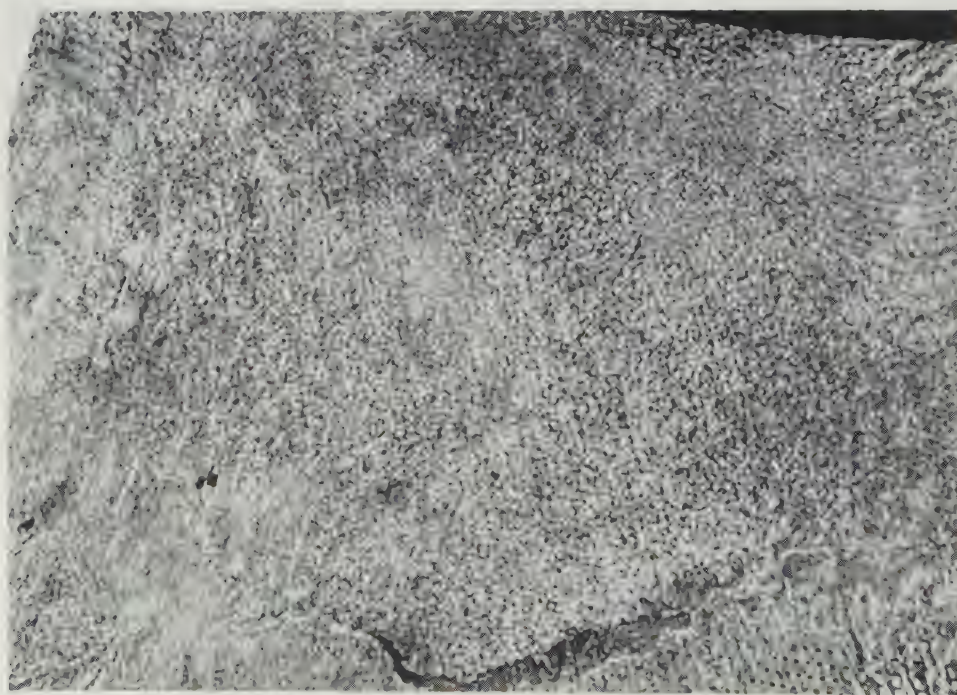


Fig. 4.8. Principal component 3 of the January 1979 scene, containing 1.3 % of the variation.

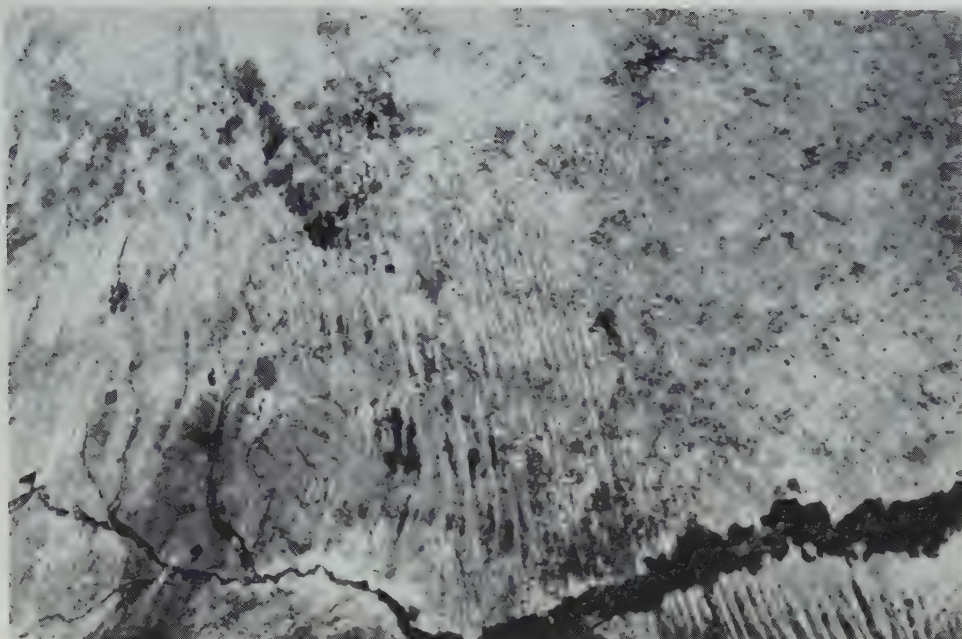


Fig. 4.9. Principal component 1 of the March 1979 scene, containing 93.1 % of the variation.

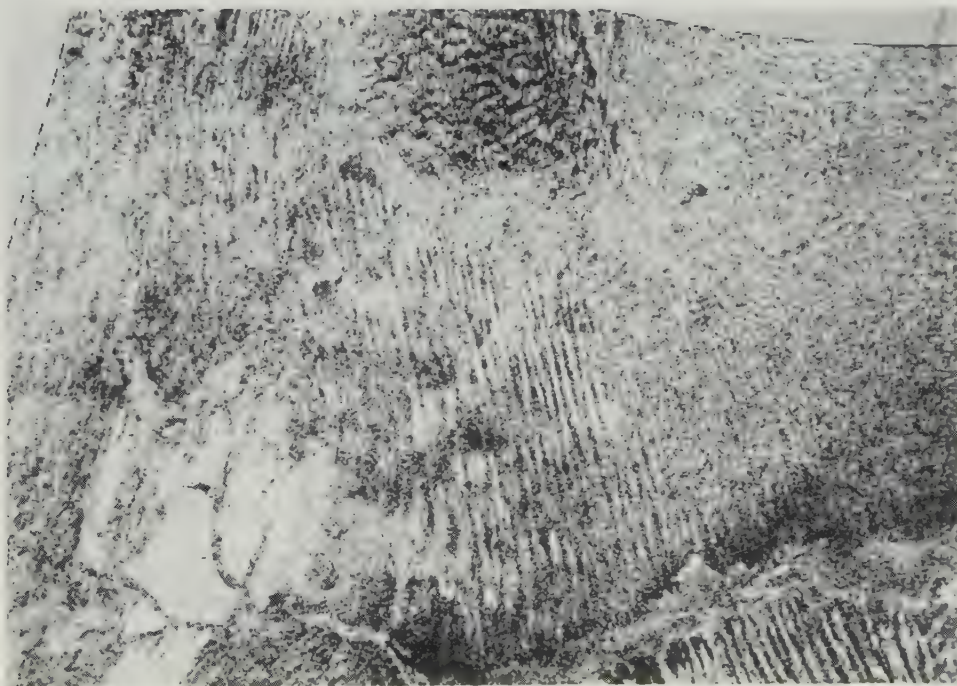


Fig. 4.10. Principal component 2 of the March 1979 scene, containing 4.5 % of the variation.

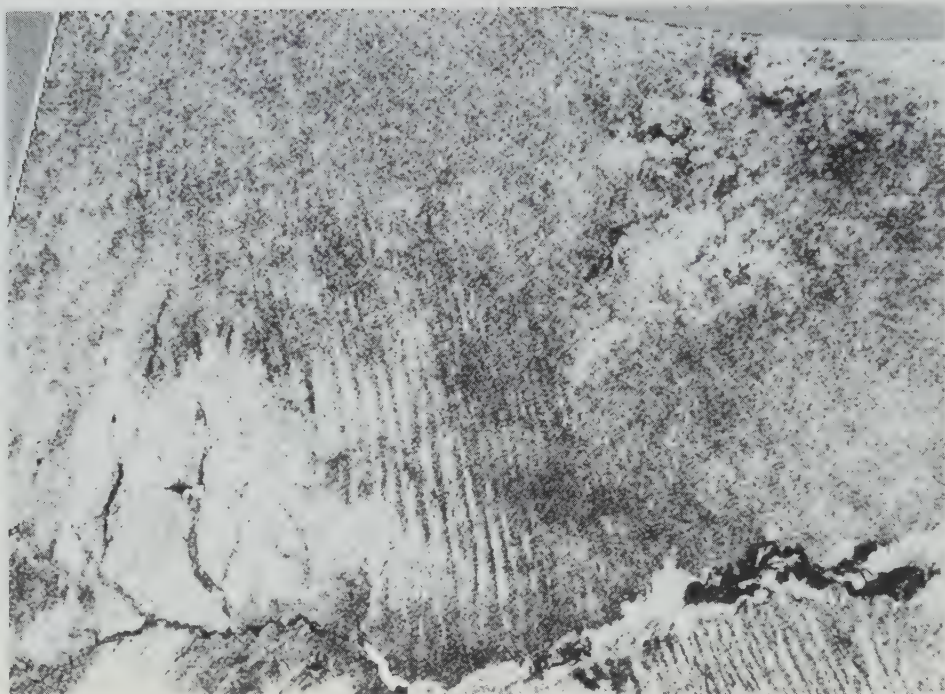


Fig. 4.11. Principal component 3 of the March 1979 scene, containing 1.7 % of the variation.

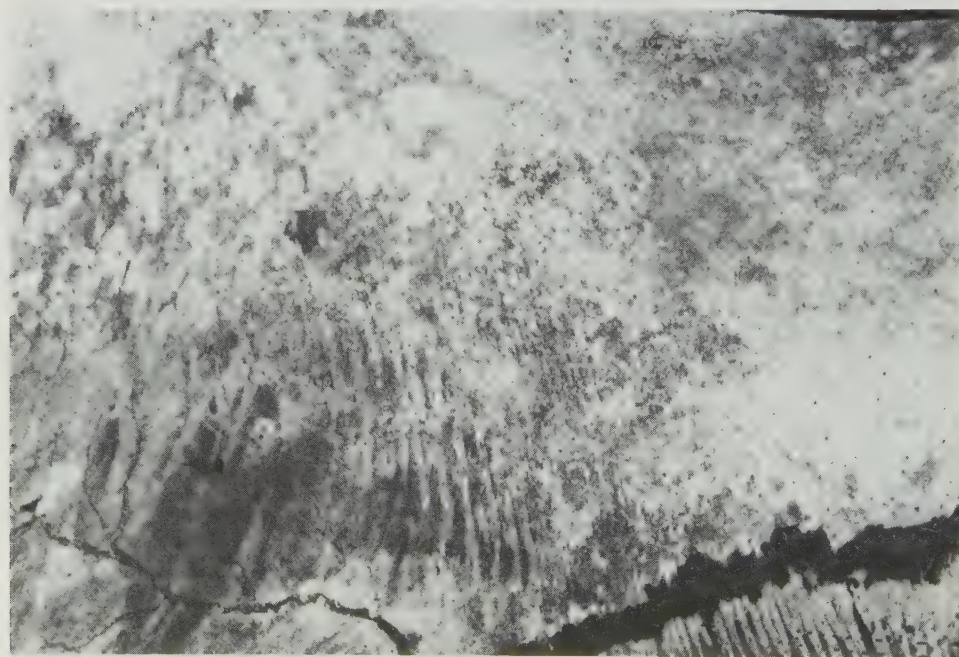


Fig. 4.12. Principal component 1 of the September 1979 scene, containing 89.7 % of the variation. Due to the presence of green biomass on the ground the component loading is lower.

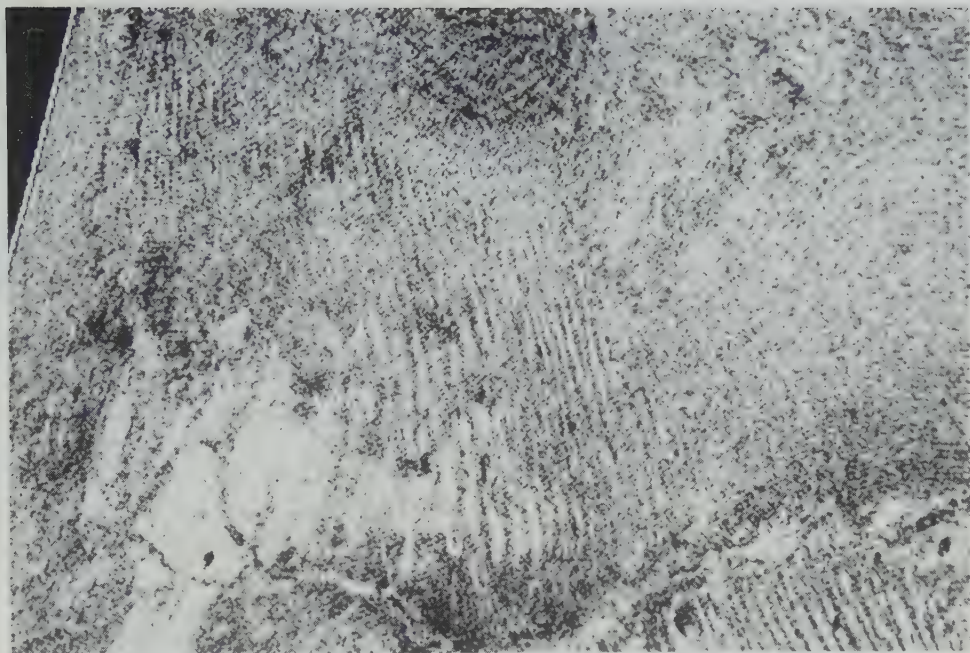


Fig. 4.13. Principal component 2 of the September 1979 scene, containing 6.7 % of the variation. Due to the comparatively high component loading, the image looks different from the dry season second components.

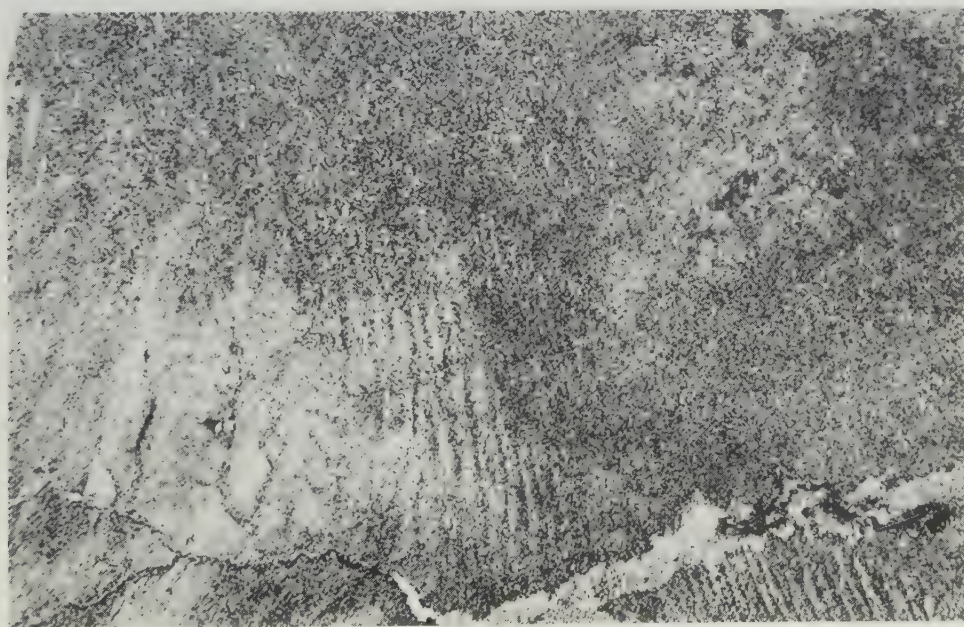


Fig. 4.14. Principal component 3 of the September 1979 scene, containing 2.8 % of the variation. This component seems to contain very little useful information. The geomorphological features, clearly seen in the dry season third components, can not be found.

An attempt to classify ever-green bush vegetation (see Fig. 4.15) was made in Olsson (1984d). It was based on multi-temporal classification from two different seasons, wet season in September and dry season in March 1979. The multitemporal analysis may very well be carried out using principal components to reduce the dimensionality, instead of the 8 bands from two images. A maximum likelihood classification of components 1 and 2 from both seasons was carried out. It resulted in substantial over-classification of the ever-green vegetation. Better results could be achieved if some of the modifications of the ML classification were done.



Fig. 4.15. Thicket of the ever-green Usher (*Calotropis procera*) ca 35 km NE of Umm Ruwaba.

Based on field data collected in 1980, 1982 and 1984, it was found that the ever-green bushes forming thicket are *Calotropis procera* (see Fig. 4.15) and *Leptadenia Pyrotechnica*. These species are confined to sandy soils. Prior probabilities of their relative frequencies were obtained by analysis of field data from Jan - Feb 1980. Of the field data points taken from sandy soils 20 % contained either *Calotropis* or *Leptadenia*. The prior probabilities were set accordingly to 0.2 and 0.8.

A digitized soil map (see Chapter 5) was used to exclude the non-sandy soils. The accuracy of the classification can be estimated from the confusion matrix, presented in Tab IV.3. The classification result is shown in Fig. 4.16. Since wet-season data from 1973 were lacking, the classification could only be effected on the 1979 data.

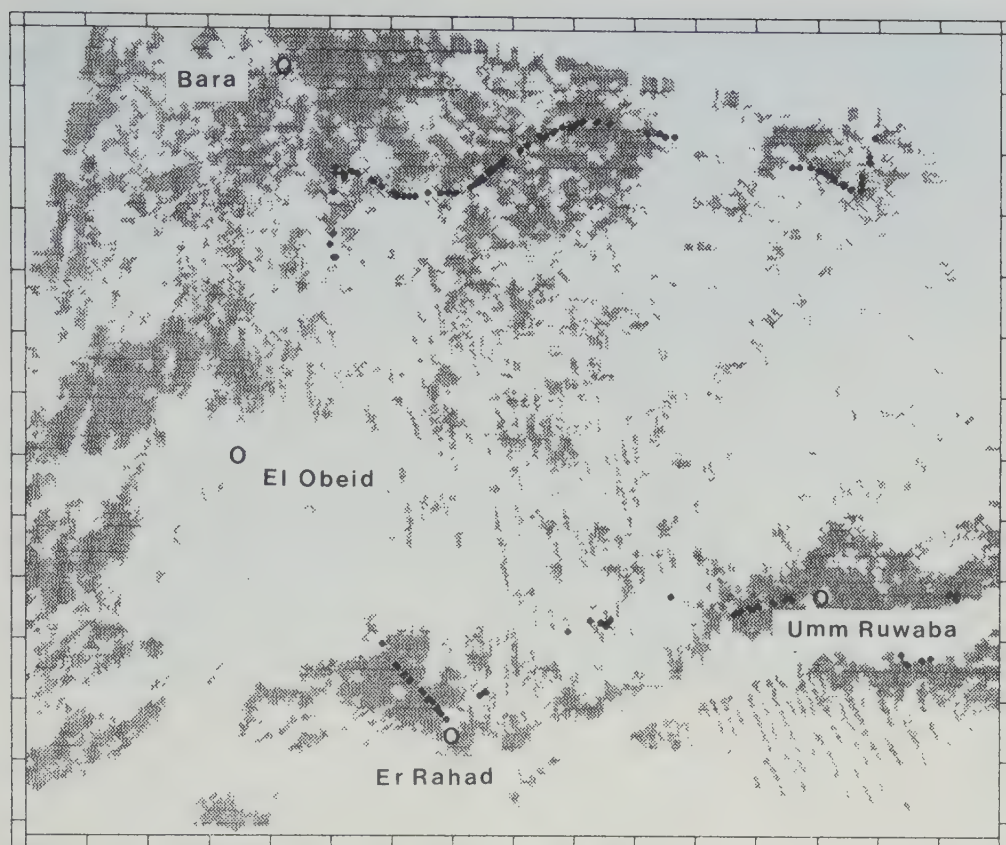


Fig. 4.16. Result of multitemporal maximum likelihood classification of ever green bush vegetation. The classification was carried out on principal components 1 and 2 of March and September 1979 images. The prior probabilities were estimated from sampled ground truth data and set to 0.2 for the ever-green bushes, and 0.8 for the other class. A mask covering fine-textured soils was used for exclusion areas where the probability of finding the species under consideration was low. Field data points containing ever-green bushes have been superimposed

Tab. IV.3. Confusion matrix showing classification result from ML classification of ever-green bush vegetation.

		FIELD DATA POINTS		
		EVER-GREEN	OTHER AREAS	SUM
M A P	EVER-GREEN	98	17	115 (32.6%)
	OTHER AREAS	24	213	237 (67.3%)
	SUM	122 (34.7%)	230 (65.3%)	352

Several means for estimation of classification accuracy have been described by different authors, e.g. Hord & Brooner (1976), Hay (1979) and Hellden (1979). Since there is no generally accepted methodology for accuracy estimation, I have chosen to present the data as a confusion matrix only. We can see that, of the field data points corresponding to ever-green vegetation, 80 % were correctly classified, and 85 % of the map data points were correctly classified. The ever-green vegetation was under-classified by 2 %. The total number of data points used in the evaluation was 352 (35 % ever-green vegetation, 65 % other areas). I consider the result to be very satisfactory.

3.1.3 Albedo Mapping

Albedo can be defined as "the ratio of the amount of electromagnetic radiation reflected by a body to the amount incident upon it, often expressed as a percentage, as, the albedo of the Earth is 34 %.... Albedo may refer to the entire solar spectrum or merely to the visible portion" (Reeves 1975, p 2064). According to Reining (1978), relative reflectance, i.e. albedo, could be a possible indicator of desertification. Otterman (1974), Otterman & Fraser (1976), Otterman et. al. (1980) reported that overgrazing, cultivation and other antropogenic pressures on arid and semi-arid regions had a strong impact on surface albedo in Israel, USSR, Afghanistan and in the Sahel region. Robinove et. al. (1981) used multitemporal Landsat generated albedo images for studies of indicators of desertification. The study area could be characterized as a cold desert with very little human activity. "Most increases in albedo were due to erosion caused by flush floods. Most decreases in albedo were caused by increases in annual plant cover following increased soil moisture in wet years or by wet ground after recent rains"(ibid.). As a conclusion they suggested that the method could readily be used in areas where the changes are more drastic.

The Landsat MSS system covers wavelengths between 0.5 to 1.1 microns of the radiation from the sun. Approximately 52 percent of the total solar irradiance (0.12 - 1 microns) fall within this range.

Comprehensive investigations of atmospheric influence on satellite imagery and derivation of surface albedo from digital Landsat data were presented by Otterman & Fraser (1976) and Otterman et. al. (1980). A method for derivation of surface albedo from Landsat data only, without any atmospheric models or ancillary data on the atmosphere needed, was presented by Robinove et. al. (1981). The pixel values of MSS 4 - MSS 7 are transformed into absolute reflectivity values according to the formula in section 2.1. Albedo can then be calculated by the sum of the four MSS bands.

Albedo maps were generated, by the method described above, from January 1, 1973, January 6, 1979, March 19, 1979 and September 24, 1979. These are shown in Figs. 4.17 - 4.20. The cumulative histograms of the distribution of albedo values in percent are given in Figs. 4.21 - 4.22.

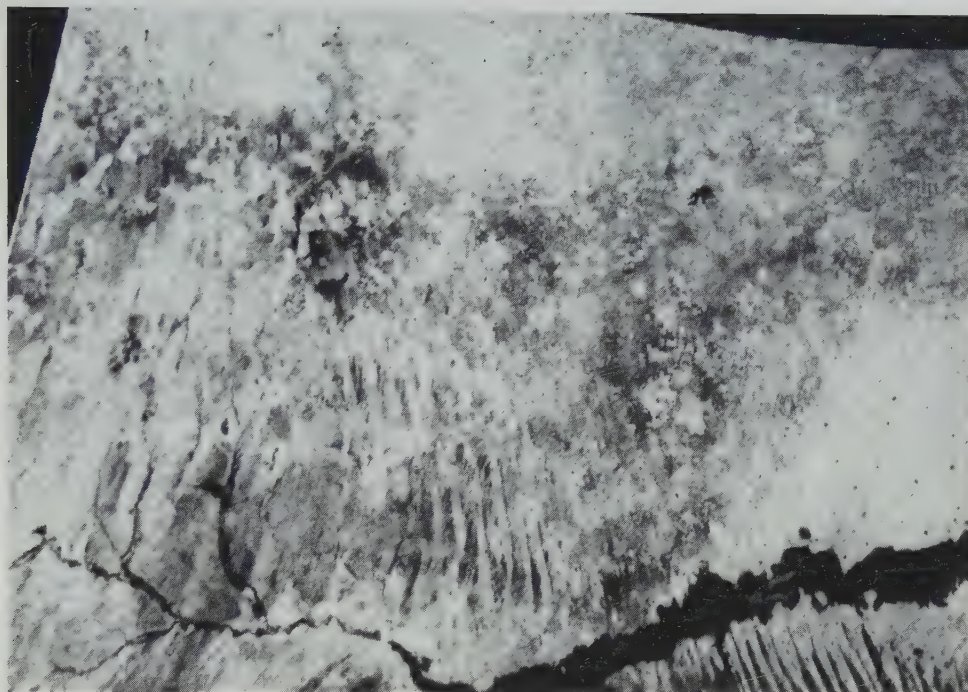


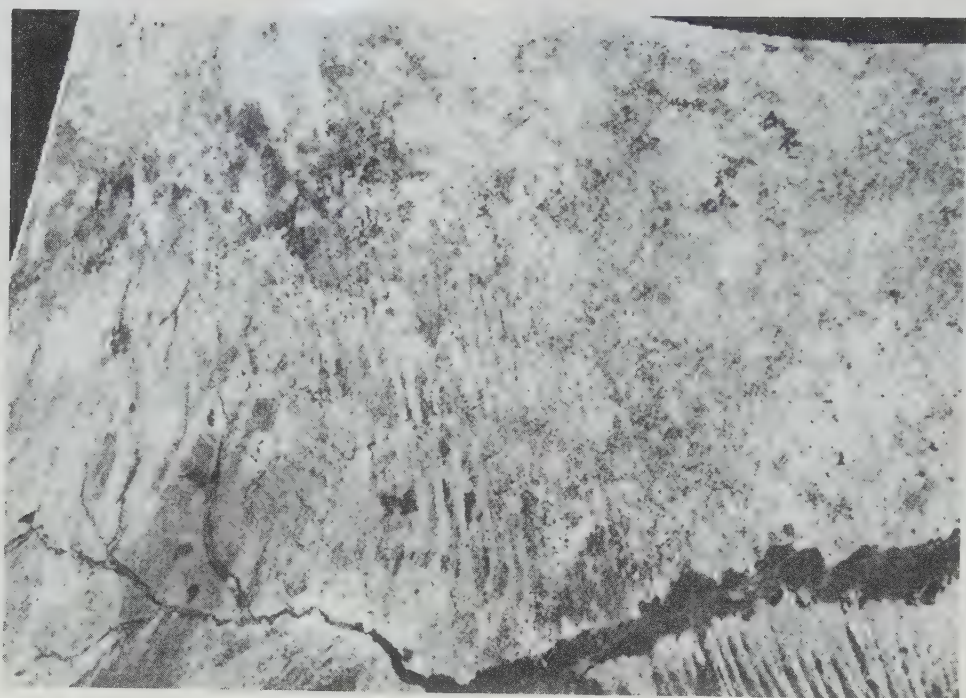
Fig. 4.17. Albedo transformation of the January 1973 scene. The highest albedo values, above 35 %, were found in the very intensively cultivated and densely populated region NE of Umm Ruwaba. The region around Bara had also very high albedo values. The preceding rainy seasons, 1970, 1971 and 1972, were drier than normal, see Fig. 9.2.

The El Obeid region on the other hand, did not show very high albedo values although it is a region of intensive land use. One reason is probably that the soil itself has much lower albedo than the very light sandy soils of the true Qoz region. Very low albedo values were found in the Khor Abu Habil basin, where the soil is an almost black cracking clay soil. El Obeid received also less rainfall than normal in the preceding years.

next page:

Fig. 4.18. Albedo transformation of the January 1979 scene. The rainfall conditions had returned to normal in 1979, and therefore we can anticipate major changes in albedo values compared with 1973. The most striking difference was that the region NE of Umm Ruwaba had decreased in albedo significantly, up to 20 units in some cases. In the Bara region the difference was however not more than 10 units on an average.

Fig. 4.19. Albedo transformation of the March 1979 scene. As the dry season proceeded the albedo increased over the entire image with the exception of the areas with bare soil in the Khor Abu Habil. The Bara region had however increased more in albedo than other regions.



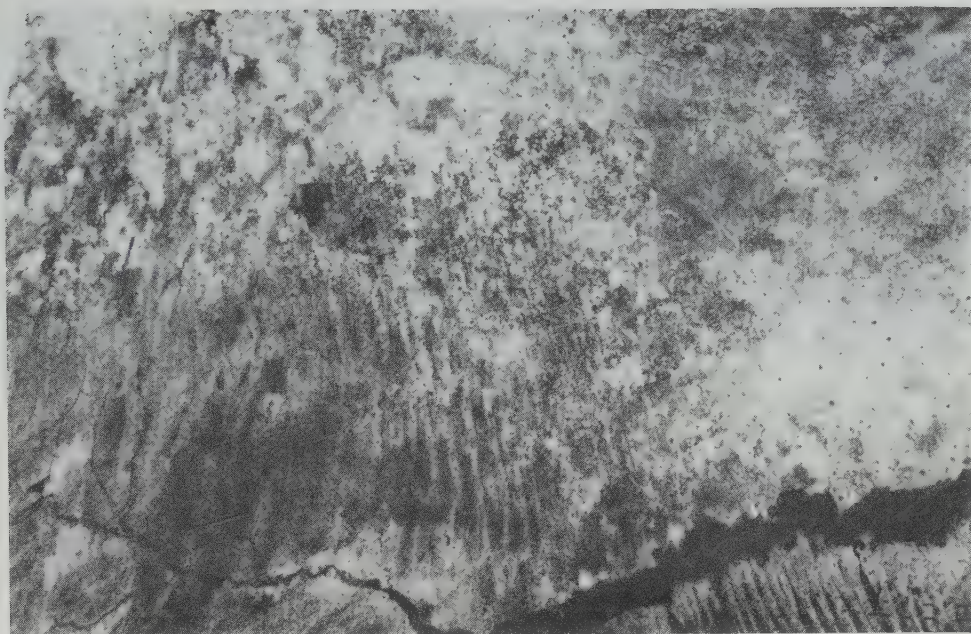


Fig. 4.20. Albedo transformation of the September 1979 scene. After a fairly good rainy season, the albedo values decreased as a whole. The same pattern did however exist, high albedo values in the intensively cultivated regions around Bara and NE of Umm Ruwaba.

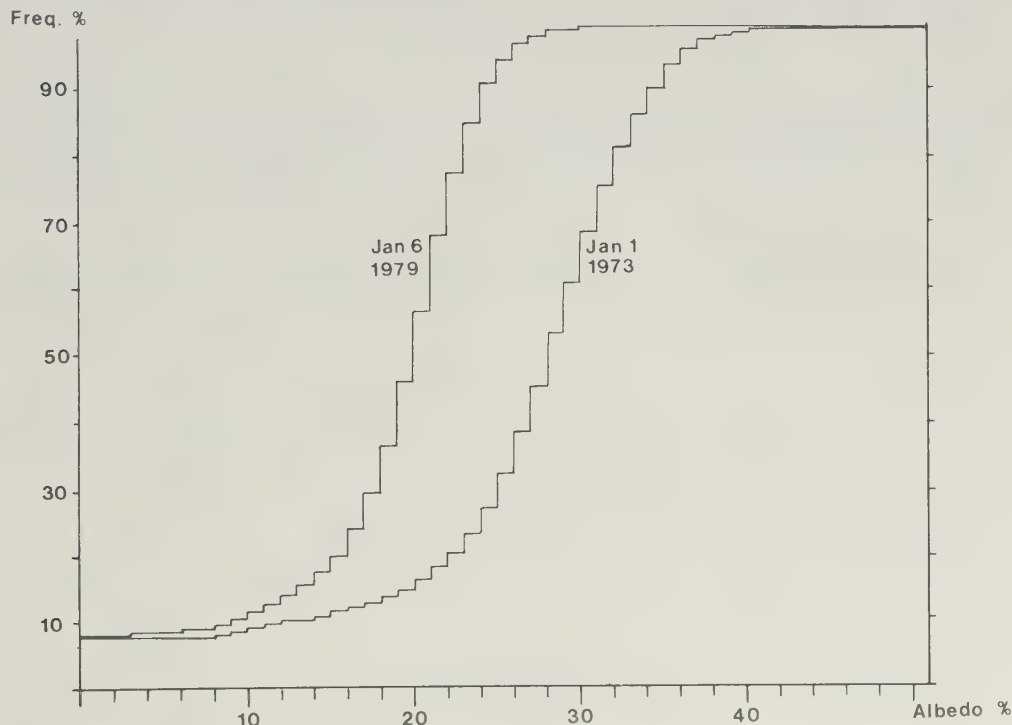


Fig. 4.21. Cumulative histogram of the albedo transformations from January 1973 and January 1979.

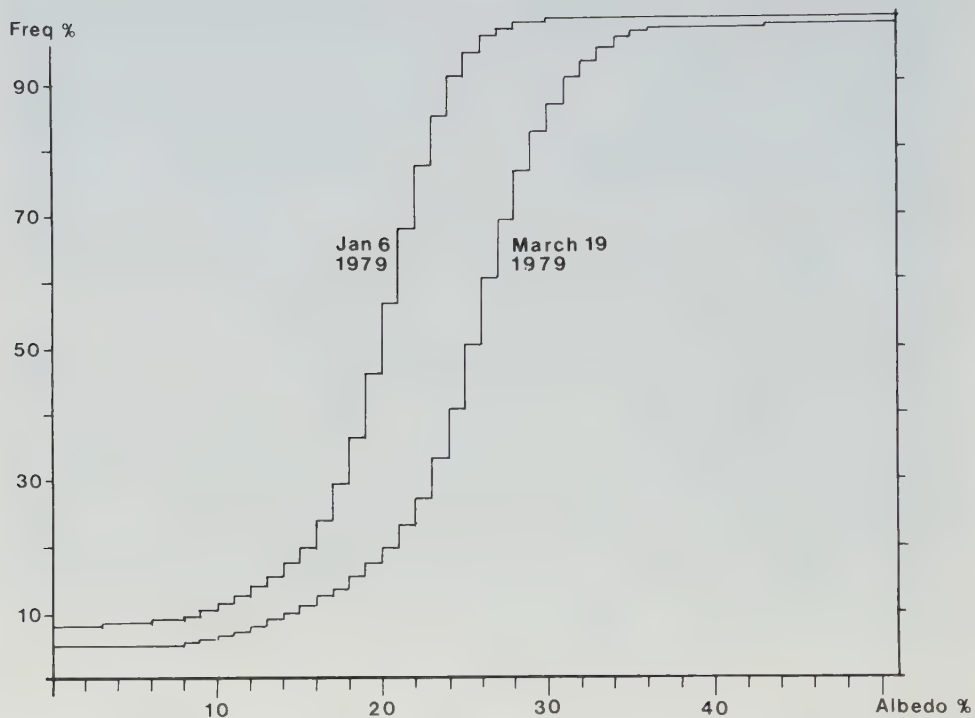


Fig. 4.22. Cumulative histogram of the albedo transformations from March 1979 and September 1979.

In order to study albedo changes over time, albedo differences were created by subtraction of two images. An offset of 100 in the subtraction was used, which means that DGL = 100 corresponds to no change. The albedo change images are shown in Chapter 9, Figs. 9.2 - 9.4.

The computed albedo values (medians: 1/1 1973 = 29, 6/1 1979 = 21, 19/3 1979 = 25) can be compared with other measurements shown in Tab. IV.4.

Tab. IV.4. Surface albedo values calculated for different arid regions (in per cent).

Sinai (Otterman & Fraser 1976)	0.47 - 0.52
Arabian Peninsula (Kondratyev et. al. 1974)	0.28 - 0.32
Sahara (ibid.)	0.21 - 0.30
Sahara (Pytovskaya 1974)	0.23 - 0.36
Sonora Desert, Arizona (Kung et. al. 1964)	0.22
Desert, S.E. California (ibid)	0.27 - 0.28
Desert near Las Vegas, Nevada (ibid)	0.24 - 0.27
Thar desert, India (Bryson 1974)	0.20 - 0.22
S.W. Utah (Robinove et. al. 1981)	0.25 - 0.30

There seems to be a fairly good correspondence with most of the other measurements from arid regions except for Sinai. Otterman & Fraser (1976) discuss possible explanations for the large difference between their measurements and most others. One is the time of the day when the measurement is carried out (Landsat ca. 0930). The most important difference, however, was assumed to be that the older measurements did not fully account for the infrared part of the albedo.

The method applied in this report is not as accurate as the one applied by Otterman & Fraser (1976), and is probably best suited for studies of relative changes rather than absolute measurements.

3.1.4 Biomass Indices

The spectral reflectance of green vegetation is distinctive and very much dependent on wavelength. Fig. 4.23 shows a typical spectral reflectance pattern of green vegetation. The chlorophyll absorbs radiation in the visible part of the spectrum, with an absorption peak in 0.65 microns. The reflectance is on the other hand very high in the near infrared (NIR) parts of the spectrum. The Landsat MSS bands can be combined in different ways in order to enhance the green vegetation signature. A ratio between a NIR band (MSS 7 or MSS 6) and a visible band (MSS 5 or MSS 4) will be very sensitive to changes in the "green-vegetation-signature".

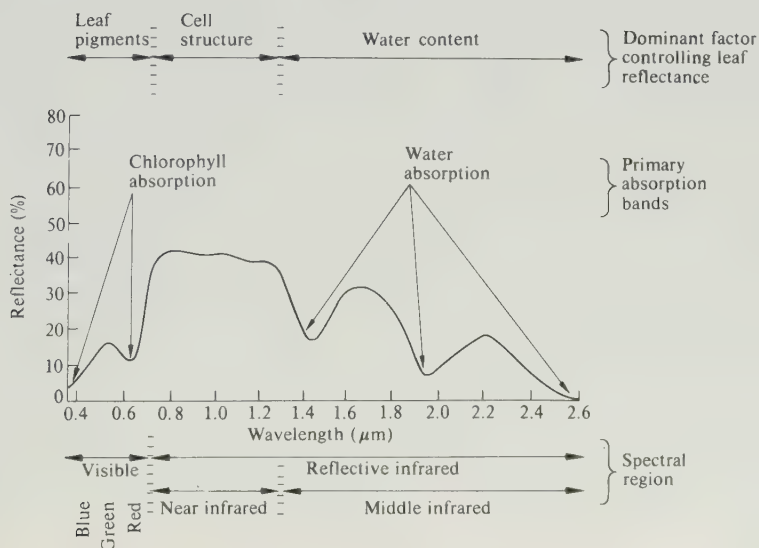


Fig. 4.23. Significant spectral response characteristics of green vegetation. From Hoffer (1978)

A large number of vegetation indices or biomass indices, based on the NIR/visible red ratio, have been developed and tested by numerous authors e.g. Richardson & Wiegand (1977), Wiegand & Richardson (1982) Pollock & Kanemasu (1979) and Tucker (1979). The most important of these are listed in Tab. IV.5.

Tab. IV.5. Some commonly used vegetation indices

Ratio Vegetation Index (RVI)	$MSS7 / MSS5$
Ratio Vegetation Index (RVI6)	$MSS6 / MSS5$
Vegetation Index (VI)	$(MSS7-MSS5)/(MSS7+MSS5)$
Transformed Veg. Index (TVI)	$(MSS7-MSS5)/(MSS7+MSS5)+0.5$
Vegetation Index (VI6)	$(MSS6-MSS5)/(MSS6+MSS5)$
Transformed Veg. Index (TVI6)	$(MSS6-MSS5)/(MSS6+MSS5)+0.5$
Green Vegetation Index (GVI):	
	$-.29*MSS4 - .56*MSS5 + .6*MSS6 + .49*MSS7$

Very high correlation coefficients (0.86 - 0.90) were obtained by Tucker (1979) between wet biomass and three different vegetation indices when using hand-held radiometer. Correlation coefficients between Landsat data and vegetation parameters were not as good (0.6 - 0.7) but still 95 % significant (Richardson & Wiegand 1977).

A combination of transformed normalized difference (TND) $(MSS7-MSS5)/(MSS7+MSS5)$ and two different scaling approaches was used by Hellden (1984) to monitor green vegetation in N. Kordofan Province, the Sudan. The first scaling approach was described under 2.1. The second approach, valid with the same assumptions as approach one, used scaling of the TND image to 0 - 200. The TND data were not correlated with any ground measurements of biomass, but with rainfall data for regions around meteorological stations. A previous study (Olsson 1983) had showed the very high correlation between rainfall characteristics and yield of rain-fed crops in the same area. The correlation coefficients between TND and rainfall (sum of July, August and September) were approximately 0.8 for both approaches. In Fig. 4.24 and 4.25 the TND from the March and September images are shown. Biomass values above 100 are supposed to represent green healthy vegetation, while values below 100 represent dry vegetation and bare soil.

The soil brightness line and the greenness line (see Richardson & Wiegand 1977 and Wiegand & Richardson 1982) were calculated in the wet season (September) image using the Gram-Schmidt process (Freiburger 1960). The scatterplot between MSS 5 and MSS 7, together with the greenness and brightness lines, is shown in Fig. 4.26.

The different biomass indices tested were all highly correlated to each other. The correlation matrix of different biomass

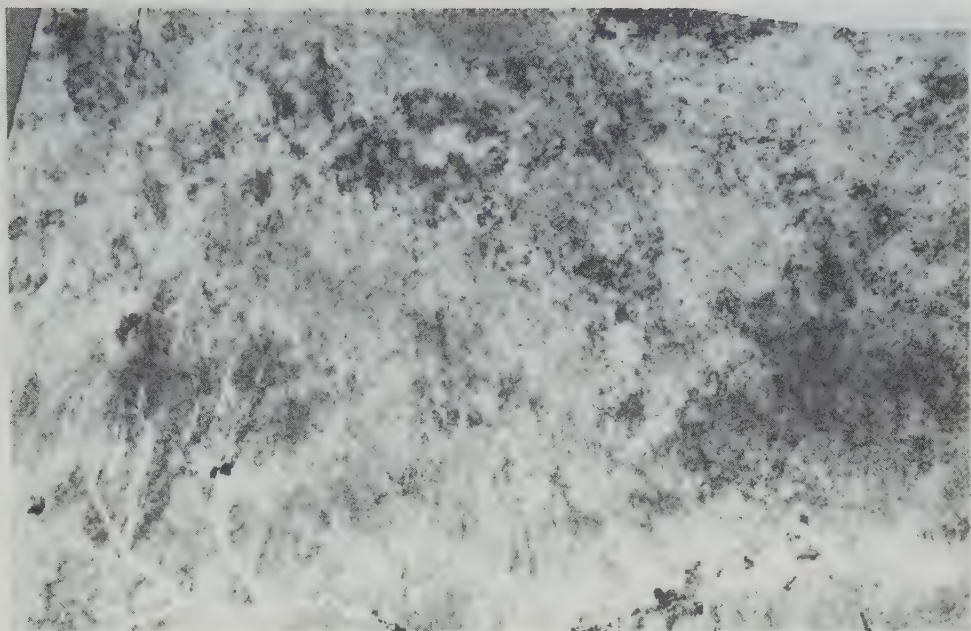


Fig. 4.24. Transformed normalised difference image from September 1979. Most of the image had values over 100, i.e. green biomass. Areas in the vicinity of El Obeid and areas North and NE of Umm Ruwaba were very low in biomass.

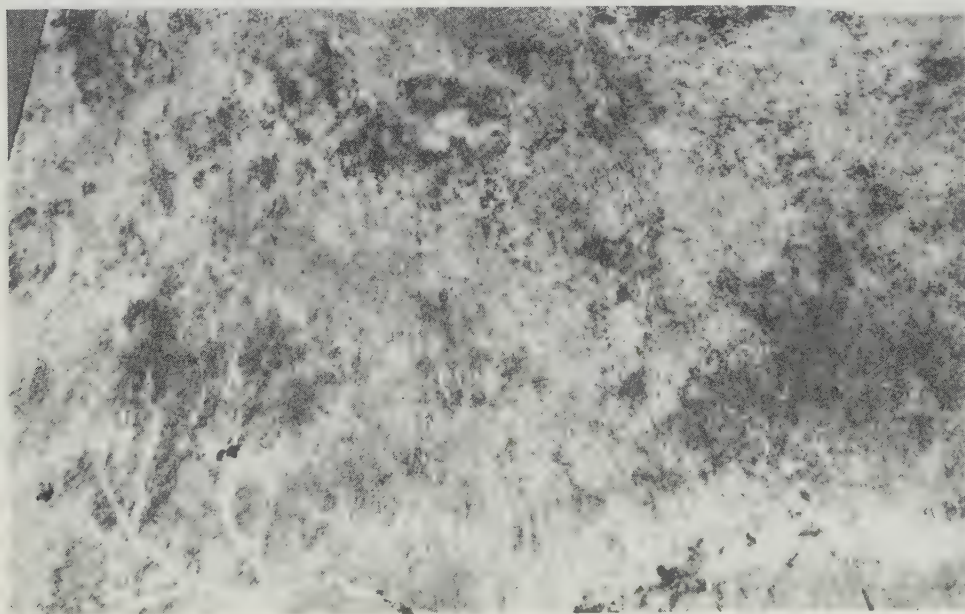


Fig. 4.25. Transformed normalised difference image from March 1979. Almost the entire image showed TND values below 100, i.e. dry vegetation or bare soil. Only some areas in the main wadi system showed TND values over 100. The ever-green bush vegetation contained not enough green healthy biomass to give values over 100.

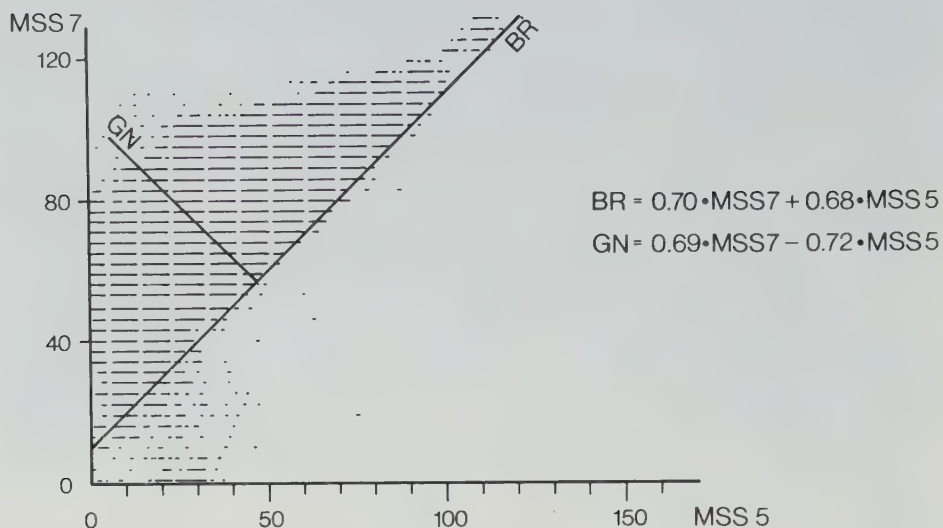


Fig. 4.26. Scatterplot between MSS 7 and MSS 5 of the September 1979 image. The soil brightness (BR) and the greenness (GN) lines are indicated.

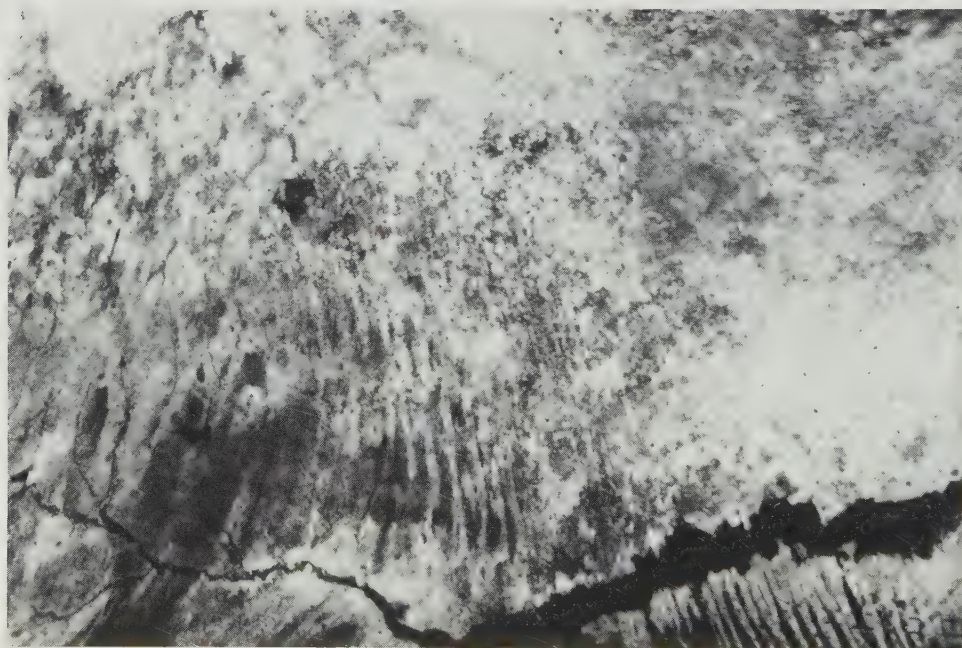


Fig. 4.27. Soil brightness transformation of the September 1979 image. The brightness transformation is akin to the first component of a principal component transformation, though the brightness contains only information from two wavelength bands, MSS 7 and MSS 5.

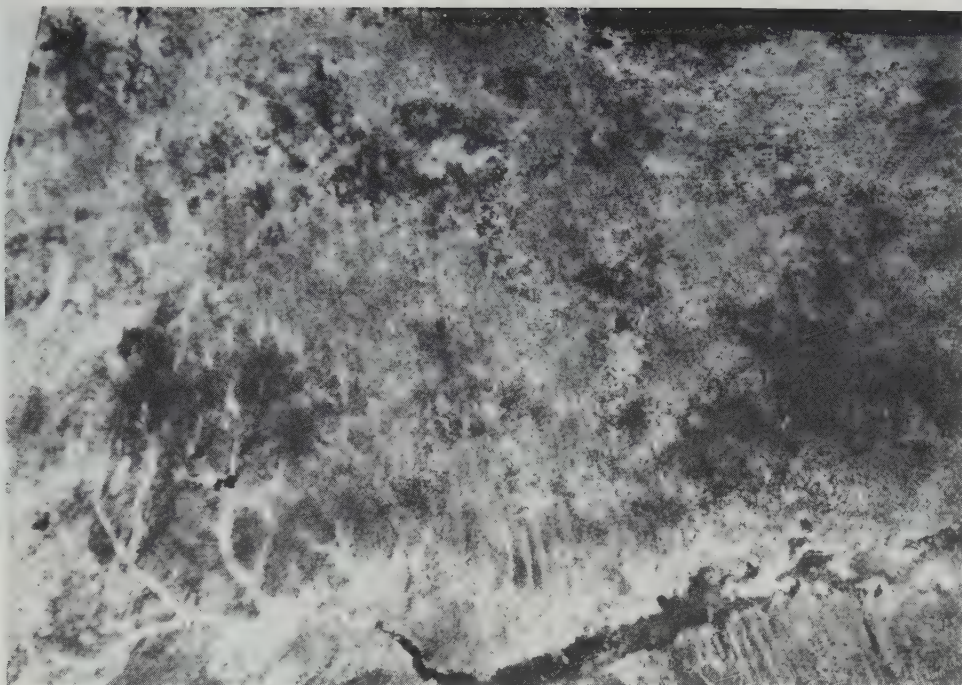


Fig. 4.28. Greenness transformation of the September 1979 image. The greenness transformation showed very much the same features as the other biomass transformations. The major difference from the TND image was that the greenness did not show the Khor Abu Hahl area as bright as the TND did.

indices and principal component 2 of the September 1979 image is shown in Tab. IV.6.

Tab. IV.6. Correlation matrix for 5 different biomass indices and principal component 2, of the September 1979 scene.

	RVI	RVI6	VI	VI6	GN	PCA(2)
RVI	1.00					
RVI6	0.92	1.00				
VI	0.77	0.71	1.00			
VI6	0.82	0.92	0.82	1.00		
GN	0.62	0.60	0.92	0.73	1.00	
PCA(2)	-0.55	-0.66	-0.90	-0.81	-0.95	1.00

The brightness and the greenness images are shown in Fig. 4.27 and 4.28.

The relationships between the image transformations and sampled field data are presented in the Appendix and discussed in section 5.

3.2 Texture Information

The treatment of spatial information in digital image processing of remotely sensed data is relatively new. We can distinguish two different approaches in spatial processing, image enhancement and texture analysis.

Image enhancement is done in order to prepare an image for visual interpretation. The aim can be to either enhance spatial details or suppress them. Texture analysis, on the other hand, comprises various techniques for the transformation of spectral images to non-spectral images, consisting of information on the spatial variation in the spectral image.

The literature on texture analysis is rich and continuously expanding. The number of ways of describing spatial variations within an image are only limited by man's imagination (Townshend 1981). Comprehensive sets of textural measures for remote sensing applications were described in Haralick & Shanmugam (1974), Hsu (1978) and Irons & Petersen (1981).

A cultivated region can be characterized by its high degree of texture, see Fig. 4.29. The ground is divided into a patchwork

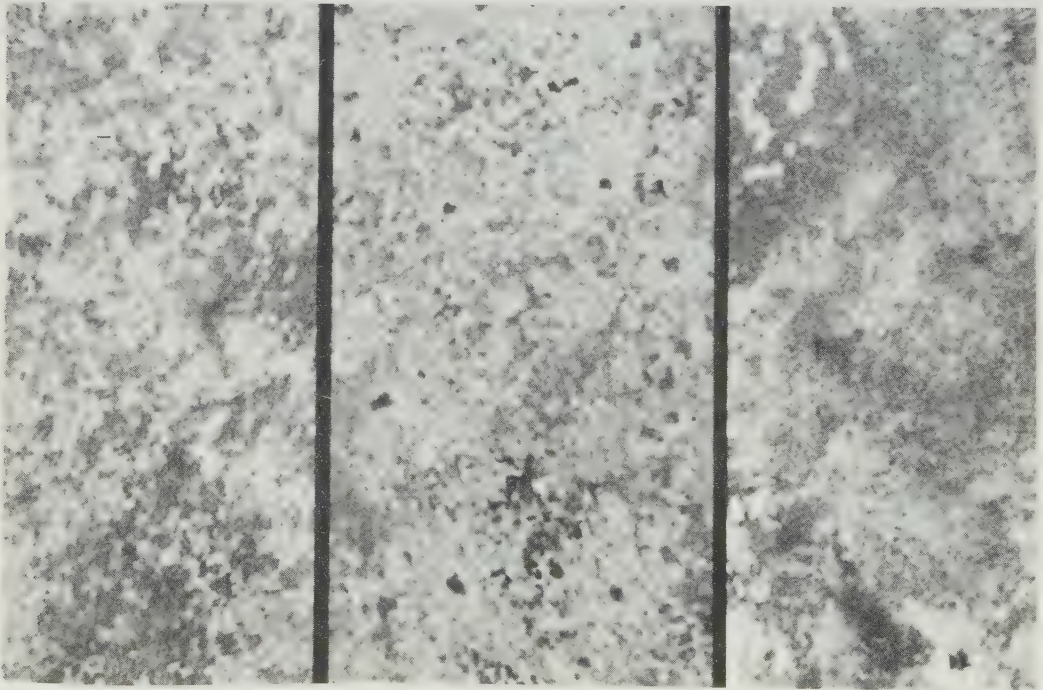


Fig. 4.29. Sections of MSS 5 (March 1979) showing a typical cultivation pattern with fairly large fields (A), with small fields (B) and an area not subject to cultivation at all (C).

of cultivated fields and natural vegetation. In many parts it is easy to distinguish between cultivated and non-cultivated areas. The human perception of texture, however, makes it difficult to objectively make this distinction. Texture perception was investigated by Hsu & Burright (1980). Richards (1978) using "random-dot" patterns found, that a pattern with 63 grey levels is not perceptually different from one consisting of only three grey levels.

For the study of cultivation patterns and separation between cultivated and non-cultivated areas a number of textural measures have been developed and tested. The standard deviation of rather large filters (e.g. 15 x 15 pixels), gave a fairly good result, in the separation of homogeneous areas. The number, or frequency, of deviations from the centre pixel in equally sized filters yielded similar results, though the amount of speckle in the image was substantial. In order to remove the speckle, the filtered image had to be smoothed by e.g. a mean, median or mode filtering. The texture transformations are presented in Figs. 4.30 and 4.31.

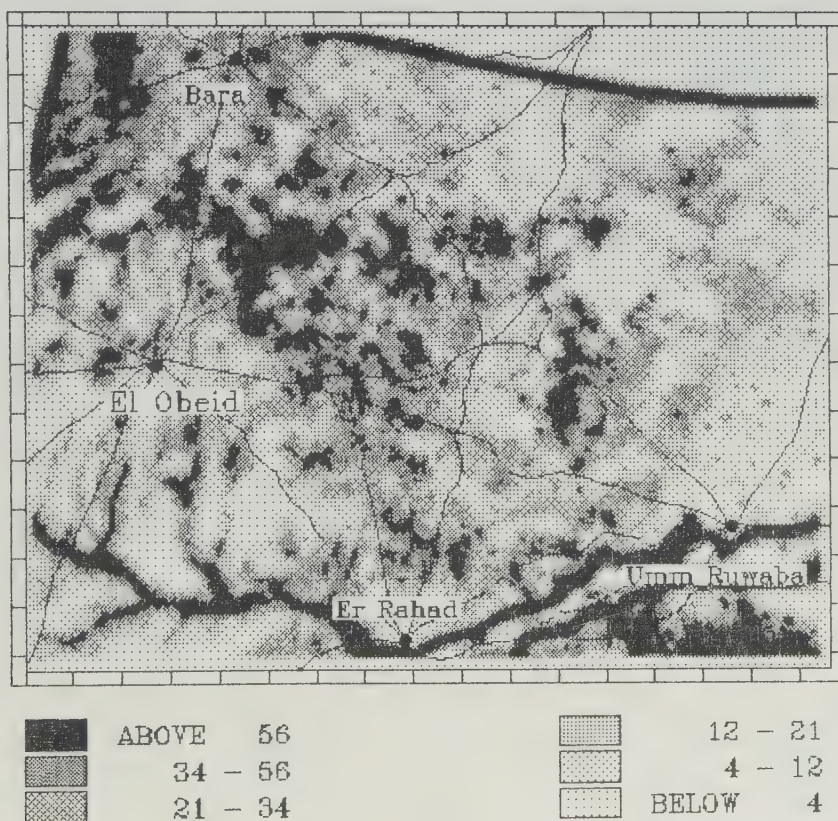


Fig. 4.30. Frequency filtered component 1 from the January 1973 scene. The filter size was 15 x 15 pixels, and the minimum level of deviations of DGLs from the center pixel was 15. The frequency image was subsequently median filtered with a filter size of 5 x 5 pixels.

The highest texture values could be found in two types of regions, regions where the sand dune pattern was very prominent, e.g. south of Umm Ruwaba and in the Kheiran region west of Bara, and in regions where the cultivation pattern was prominent, i.e. where the natural vegetation was dense enough to contrast with the light bare soil of cleared fields.

Low texture was found in two principally different regions, where the land use was extremely intensive, and in areas very sparsely populated. The area NE of Umm Ruwaba was a very densely populated area with intensive cultivation. The very intensive cultivation in combination with the very low rainfall in the preceding rainy season of 1972, caused probably severe over-exploitation. The cultivation pattern was erased, i.e. there was either no areas in fallow, or the fallow fields contained no or very little vegetation. The other type of low texture area was found in the NW part of the image, where there

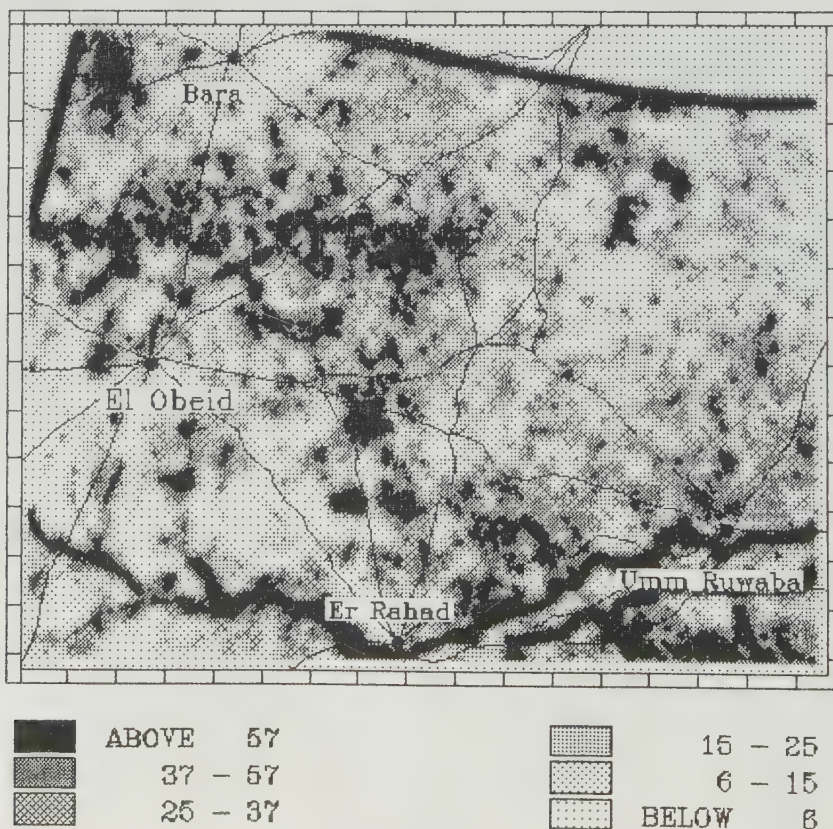


Fig. 4.31. Frequency filtered component 1 from the January 1979 scene. The filter size was 15 x 15 pixels, and the minimum level of deviations of DGLs from the center pixel was 15. The frequency image was subsequently median filtered with a filter size of 5 x 5 pixels.

was no intensive cultivation. Except for the high texture caused by the drainage pattern, the area in the SW part of the image was very low in texture. This was due to dense bush vegetation with very little human activities.

The main difference from the 1973 texture image was that the texture had increased in the area NE of Umm Ruwaba. It is most likely a sign of regeneration of the vegetation, and that the cultivation pattern had returned. The areas in the NE part of the image had decreased in texture, probably caused by abandoned cultivated fields.

In order to study changes in the cultivated pattern from 1973 to 1979, a texture difference image was generated by subtraction of the January 1973 and the January 1979 images. The resulting image was smoothed to facilitate interpretation. The texture difference image is presented and analysed in Chapter 9.

A limitation to the texture analysis has been the very time consuming operations on a main-frame computer. To yield a good result, the texture transformations ought to be carried out on images with full resolution, i.e. 50 m pixels. Many of the textural properties have been lost when the pixel size was increased by 5 times.

4. VILLAGE INVENTORY

Detailed information on population distribution is necessary for the study of land degradation. In Sudan the censuses have been infrequent (1955/56, 1973 and 1983) and of low accuracy. The 1973 census was not reported until 1980, but due to its low accuracy it was withdrawn a few years later (Stern 1984). The most detailed data from the latest census, villages and village councils, were obtained from the Census office in Khartoum, both in map form and as tables. The aim was to use these data as a basis for the analysis of population parameters. However, it became obvious that the accuracy of the material was much too low to be useful. In Fig. 4.32, Stern (1984) compared the 1983 census map with aerial photos from 1977, in the scale of 1:20 000.

Stern (1982 and 1984) investigated the relationship between village size, measured in digital Landsat MSS data, and number of inhabitants according to interviews in 42 different villages in the Umm Ruwaba surroundings. 35 of the villages could be accurately identified on Landsat images. The correlation between number of inhabitants and village size, as measured in Landsat MSS images, was found to be between 0.85 and 0.90. In a subsequent report, Stern (1984), the correlation coefficient was 0.8, between size, measured in MSS data, and village inhabitants. The measurement of village size and correlation to number of inhabitants is comprehensively treated in Stern (1985).



Fig. 4.32. Map showing the difference between the census map from 1983 and the correct situation of villages, according to aerial photos from 1977. From Stern (1984).



Fig. 4.33. A part of the image containing 770 "village windows". Each window contains 25 by 25 pixels, with the village in the centre. The wavelength band is MSS 6 from March 1979.

A regression equation between number of inhabitants and village size was established in Stern (1985):

$$\text{Number of inhabitants} = 23.3 * \text{MSS pixels (50 m)} \quad r = 0.8$$

A village inventory of the whole Landsat image (187/51) was made, and subsequently used for the spatial models, Chapter 6. All villages in the Landsat scene were identified by their line and pixel addresses, and a 25 x 25 pixels image window was extracted around each village. The small windows were then merged together to form a greater image where all "village-windows" could be examined conveniently on the screen of an image analysis system. Fig. 4.33 shows a small part of this image. Misinterpreted villages were deleted from the image, and the number of "village pixels" were then automatically calculated by algorithms developed by Stern (1985). The resulting village map is shown in Fig. 4.34.

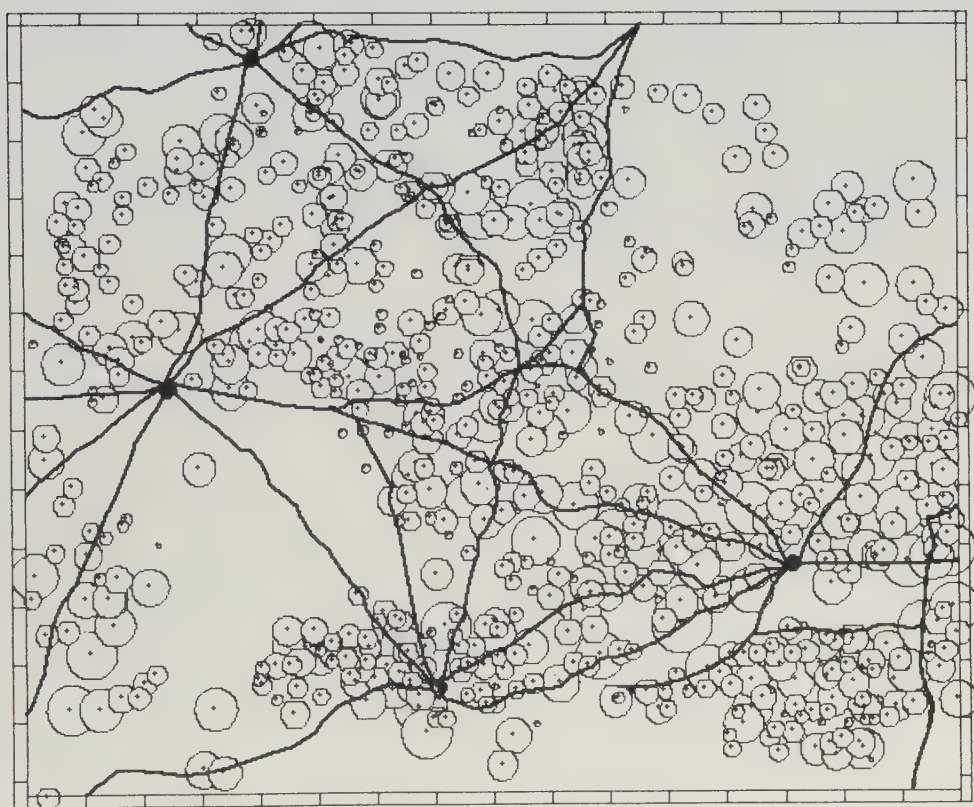


Fig. 4.34. Village map showing the size of the villages as proportional circles.



5. RELATIONSHIPS BETWEEN SAMPLED FIELD DATA AND MSS DATA

As mentioned before, I have had no access to field data from the same season as any of the four Landsat scenes used in the study. The field data from 1980 and 1982 have however been used in an attempt to investigate the relationships between some of the field data parameters described in Chapter 3, and properties of the individual MSS - bands, as well as some of the image transformations described earlier. The transformations used in statistical analysis were principal components 1 and 2 of March and September 1979 images, albedo of January, March and September 1979 and finally transformed normalised difference of March and September 1979 images.

Some of the image transformations were, not surprisingly, highly intercorrelated, a correlation matrix of the different transformations is presented in Tab. IV.7.

Tab. IV.7. Correlation matrix of some image transformations

	Albedo Jan. 73	TND Jan. 73	PC1 Jan. 73	PC2 Jan. 73	Albedo Jan. 79	TND Jan. 79	PC1 Jan. 79	PC2 Jan. 79	Albedo March 79	TND March 79	PC1 March 79	PC2 March 79	Albedo Sep. 79	TND Sep. 79	PC1 Sep. 79	PC2 Sep. 79
Albedo Jan. 73	1.00															
TND Jan. 73	0.23	1.00														
PC1 Jan. 73	0.21	0.04	1.00													
PC2 Jan. 73	0.60	-0.04	0.05	1.00												
Albedo Jan. 79	0.67	0.14	0.13	0.87	1.00											
TND Jan. 79	-0.19	-0.09	-0.13	-0.30	-0.28	1.00										
PC1 Jan. 79	0.54	-0.02	0.11	0.88	0.99	-0.36	1.00									
PC2 Jan. 79	-0.07	-0.53	0.05	-0.04	0.03	-0.99	-0.04	1.00								
Albedo Marc 79	0.70	0.17	0.15	0.77	0.92	-0.24	0.88	-0.01	1.00							
TND March 79	0.12	0.09	-0.06	-0.01	-0.09	0.33	-0.04	-0.53	0.10	1.00						
PC1 March 79	0.68	0.01	0.13	0.79	0.89	-0.35	0.90	-0.05	0.99	-0.03	1.00					
PC2 March 79	-0.10	-0.41	0.00	-0.17	-0.17	-0.36	-0.21	0.28	-0.01	-0.45	-0.05	1.00				
Albedo Sep. 79	0.65	0.15	0.10	0.69	0.76	-0.20	0.75	-0.06	0.81	0.08	0.80	-0.03	1.00			
TND Sep. 79	-0.28	-0.07	-0.11	-0.40	-0.37	0.26	-0.44	-0.34	-0.36	0.17	-0.44	-0.24	-0.54	1.00		
PC1 Sep. 79	0.63	-0.02	0.08	0.69	0.74	-0.30	0.75	-0.09	0.79	-0.04	0.80	-0.05	0.99	-0.60	1.00	
PC2 Sep. 79	-0.18	-0.51	0.01	-0.07	-0.07	-0.38	-0.10	0.28	-0.11	-0.39	-0.14	0.14	-0.02	-0.88	-0.01	1.00

The coordinates of the field data points were used to extract a window of 11 x 11 pixels around each sampled point. The rather large window of 11 pixels (equal to 2.75 x 2.75 km) was considered necessary to avoid geometrical errors due to the poor accuracy of the field data points. Since the field data points were measured in non-parametric scales, I have restricted the statistical methods to analysis of variance. The result of all the analyses is presented in the Appendix. A summary of the more interesting results is presented below. It must be remembered, however, that substantial changes can have occurred in the landscape from the time of the recording of the Landsat images in 1979 to the field data sampling in February 1982.

Vegetation Type:

In the dry season images (January 1973 & 1979 and March 1979) it was impossible to find any significant differences between the vegetation types in the individual MSS bands. The September image showed a slightly greater variation between the vegetation types, but only the types 4 and 6 were significantly different using the individual bands.

A characteristic pattern of the first components and the albedo images was that the vegetation types 0 - 4 seemed to belong to one group, and the vegetation types 5 - 7 to another one, see Fig. 4.35. The explanation to this rather surprising result is that the vegetation types 0 - 4 coincide with the Qoz region (sandy soil), and the denser types of vegetation are mostly found on the more fine textured soils. So what we actually see is two different landscape units.

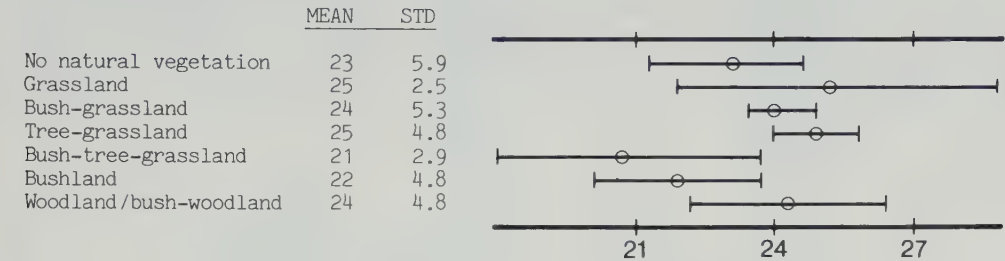


Fig. 4.35. Analysis of variance between vegetation type and PC 1 and albedo of the March 1979 image.

In the second components and the TND images this pattern could not be found. A positive relationship between TND and vegetation type should be logical to anticipate. This was however not found, the dominating vegetation types 3 and 4 showed the opposite relationship.

The multi-temporal signatures of vegetation types, as measured in components 1 and 2 of the combined March and the September images, indicated that the major vegetation types (3,4,6 and 7) could be separated. The types 2 and 5 had not enough field data points to be estimated correctly.

Canopy Cover:

All 6 individual MSS bands showed a fairly consistent trend of increasing DGLs with increasing canopy cover. The canopy cover class 4 deviate however significantly from the trend. This is likely to be due to influence from the underlying soil. The canopy cover classes 4 and higher are mostly found on the darker, fine textured soils.

The different image transformations were all fairly well related to the canopy cover, and the TND transformation showed the best relationship. TND values of both September and March show a strong relationship of increasing biomass with increasing canopy cover, see Fig. 4.36. The trend is consistent, which may indicate that the biomass index is not as sensitive to abiotic factors, e.g. soil colour as the individual MSS bands. The first components and the albedo transformations on the other hand show a significant difference between the highest canopy cover classes, only found on the darker fine textured soils, and the lower ones.

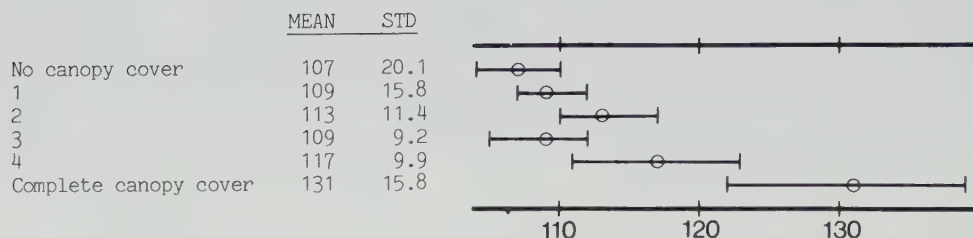


Fig. 4.36. Analysis of variance between canopy cover and TND from September 1979.

Field Cover:

All individual MSS bands showed a very consistent trend of decreasing DGLs with increasing field cover classes. On the other hand, none of the image transformations showed any significant relationship with the degree of field cover, see Fig. 4.37. This result was very surprising, and I have no plausible explanation.

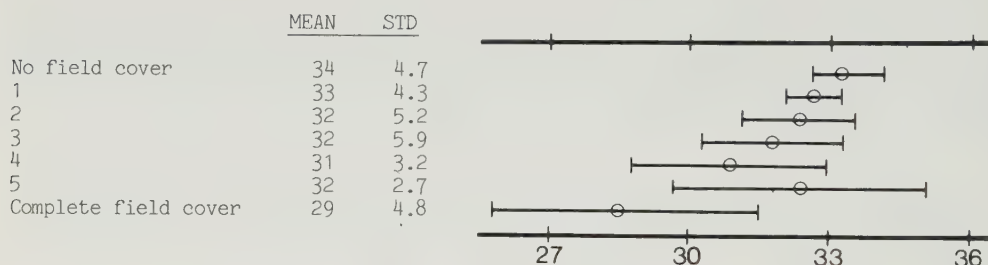


Fig. 4.37. Analysis of variance between field cover and MSS 5 September 1979.

Soil Colour and Soil Type:

The individual MSS bands of the March image, as well as the first component and albedo, were all highly dependent on both soil colour and soil type, see Fig. 4.38. The second component and the biomass index were significantly less dependent on the soil factors. This is another strong indicator of the advantages of using the ratio between near infra-red and visible red light as abiotic-independent vegetation index.

5. CONCLUSION

In this chapter various remote sensing techniques have been described, applied and tested through comparison with ground truth data. The result will be used in subsequent chapters

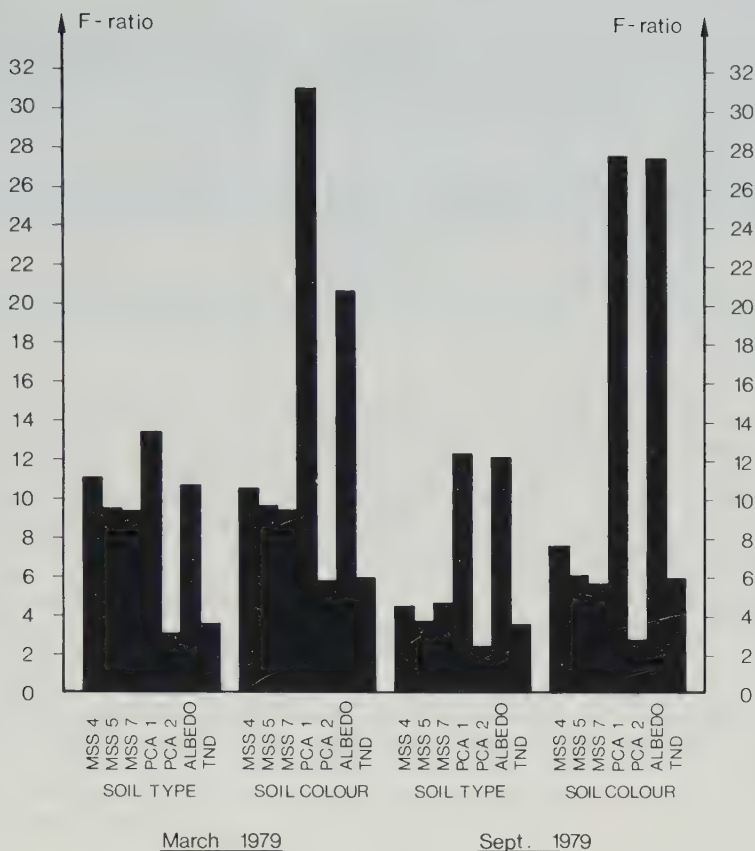


Fig. 4.38. Diagram showing the F-ratio from one-way ANOVA between different Landsat bands and image transformations on the one hand, and soil colour and soil type on the other. See Chapter 3 and Appendix for a description of the soil parameters

(Chapter 8 - 9) for studies of land degradation and distribution of resources. The main conclusions can be summarized in the following points.

1. Principal component (PC) transformation is a very efficient method for data reduction, for single scenes as well as for multitemporal images. Component 1, in the single scene case, contains typically 85 - 90 % of the total variation, and is highly correlated with the albedo transformation. Component 2 contains typically only 3 - 5 % of the variation, and is highly correlated with the biomass transformations.
2. In multitemporal classification, the first two components, together containing at least 90 % of the total variation, can readily be used instead of all the individual bands. The computer time can then be reduced substantially.

3. Multitemporal maximum likelihood (ML) classification of ever-green bush vegetation could be carried out with high degree of accuracy. The ever-green bushes, often considered as being indicators of over-exploitation and low soil fertility, are concentrated in two different parts of the study area. The most densely populated areas along the Khor Abu Habi, and in the NW part of the area, where the population pressure is high and the climatic conditions are fairly unfavourable.
4. Albedo transformations were carried out, and yielded results comparable with other measurements of drylands. Considerable changes over time have occurred, which will be analysed in Chapter 9.
5. The different biomass indices tested were all highly inter-correlated. The transformed normalised difference (TND) combined with the scaling proposed by Hellden (1984), showed a slightly higher correlation with sampled ground truth than did the other ones. Canopy cover and biomass indices showed a consistent positive relationship.
6. Through analysis of variance between sampled ground truth and different image transformations, it was found that soil type and soil colour were the most important field data parameters. This was evident through the very strong relationship with principal component one. The TND was less sensitive to the soil parameters than were the individual MSS bands.
7. The correlation between image data and ground truth data suffered most likely, from the poor geometrical precision of the field data. More significant relationships can be expected with more accurate ground truth.

five

Geographical Information System (GIS)

1. INTRODUCTION

Geographers have a long tradition of analysis of spatial data in map form. Spatial correlation between different landscape features has been analysed by comparison of thematic maps, remotely sensed images and field data of the same region. When the number of maps and images increases, the resolution becomes better and multi-temporal analysis is required, the manual methods of comparison become impossible to use. A geographic information system (GIS) is a computer-based system for storage, analysis and presentation of spatial data. Large volumes of spatial data can be handled and analysed. New information can be generated by the combination of several existing information types.

The spatial data can be stored and handled in a GIS in two principally different forms, vector and raster form, see Fig. 5.1. In vector form the data is spatially determined by coordinates, e.g. a road in vector format is determined by a series

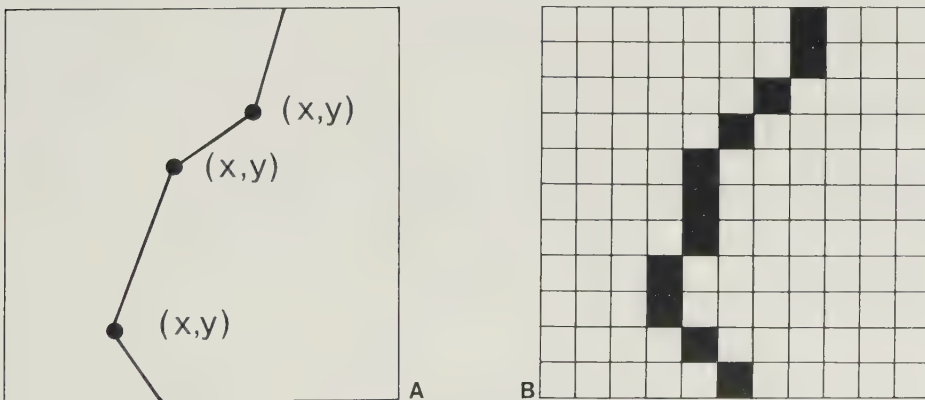


Fig. 5.1. The principle of vector (A) and raster (B) representation of spatial data.

of coordinate pairs (x,y) or triplets (x,y,z). In raster format, the same road would be represented as a series of filled grid cells. Remote sensing data, e.g. satellite images are typical raster data while digitized roads from a map are preferably represented as vectors.

In a GIS it is often advantageous to be able to treat both raster and vector data. Spatially continuous information, e.g. a soil map, is represented in raster format, while point data or aggregated areal data, e.g. village inhabitants or total number of livestock in a region, are represented in vector form.

The GIS developed and used for this thesis consists of two subsystems, the raster data base (RDB) and the vector data base (VDB). Fig. 5.2 shows the principle of the two subsystems.

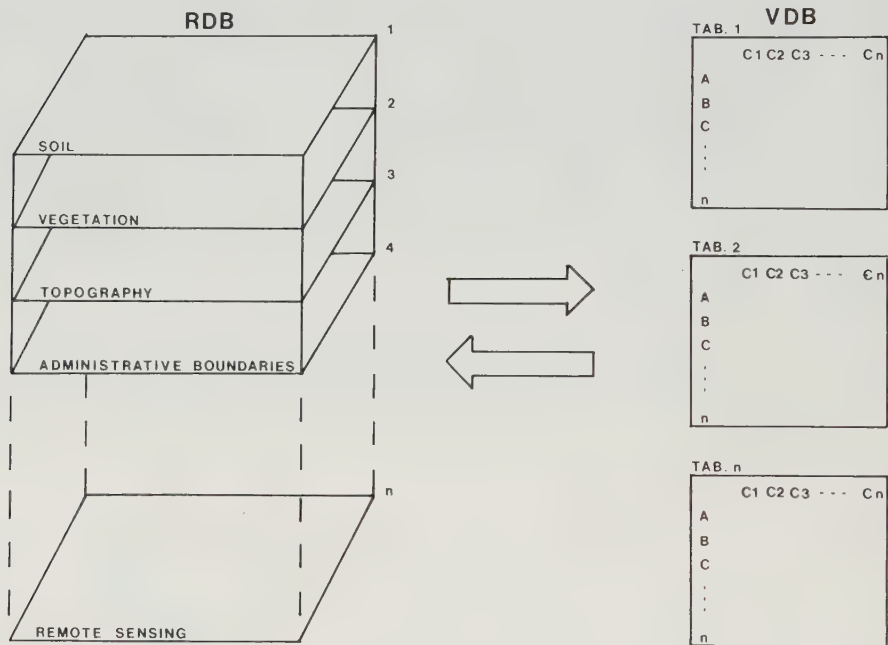


Fig. 5.2. The principle of the GIS with the raster data base (RDB) and the vector data base (VDB)

2. DATA CAPTURE

Different sources of data require different ways of processing to be used in a GIS.

1. Data already in raster format, e.g. satellite data on CCT, need only to be geometrically corrected to the reference system.

2. Tabular coordinate data, e.g. field data points, soil samples, number of inhabitants in towns and villages, need to be geometrically registered to the reference system.
3. Tabular areal data, e.g. census data per district, need to be linked to a polygon in the VDB or to a thematic information layer in the RDB.
4. Thematic maps must be digitized and either be stored as polygons in the VDB or as a thematic information layer in the RDB. The most common way of digitization is through digitizing table. Topographic maps containing large volumes of elevation data are preferably digitized automatically through e.g. automatic line follower (see e.g. Hall & Olsson 1984).

3. DATA STORAGE AND MANAGEMENT

3.1 The Raster Data Base (RDB)

In the raster data base, the information is stored as separate information layers. All of them having identical geometry, although the grid size may be different. For information layers with different grid size, a transformation of pixel addresses is necessary.

3.2 The Vector Data Base (VDB)

The data in vector form, stored as coordinates, may be linked to the raster data in two ways, by the coordinates (correspond to the pixel addresses in the raster data base) or by the values (correspond to a certain theme in the raster data base). For more complex data bases, it is necessary to use special data base management systems (DBMS) to make this communication efficient.

Searching and retrieval of data can be carried out on coordinates as well as on values.

3.3 Vector to Raster and Raster to Vector Conversion

Polygons in vector form can be transformed to thematic information layers in raster format through vector-to-raster conversion. A common way of storing polygons is to transfer x and y coordinates into a chain code (see e.g. Freeman 1980 and Monmonier 1982). This form of storage is, however, not as appropriate for areas as for lines (Freeman 1980).

The algorithm for transformation of polygons in vector form to raster data developed for this thesis is based on x and y coordinates. One advantage of this algorithm is that holes in polygons are easily handled. The conversion is carried out in the following steps, see also Fig. 5.3.

1. The area is digitized (node points) as closed polygons, i.e. the first and the last coordinate pairs are equal. Any holes in a polygon are marked by a coordinate pair.
2. The node points of the polygons are sorted into a regular raster. The equations of straight lines between all the node points are successively calculated. The grid cells along these lines, as well as the node points, are given the value 2.

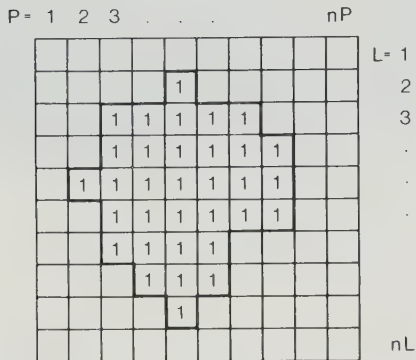


Fig. 5.3. The principle of the vector-to-raster conversion.

3. The raster is then searched, starting from the left side of the lines (the search starts in line 2), for all grid cells with a value of 0 (zero-cells), i.e. outside or inside a polygon. If a zero-cell has a non-zero cell in position L-1 and P-1, this zero-cell is assumed to be inside a polygon, and is given the value 1.
4. The raster line is now searched, from the right side to the left side, for grid cells with value 1 (one-cells). If a one-cell has a non zero cell in position L-1 and P+1, this one-cell is assumed to be inside a polygon and keeps the value 1, otherwise it will change value to 0.
5. Any holes in polygons are now processed. The coordinate pairs of the holes are sorted into the raster and given the value 0.
6. The same procedure (steps 3 and 4) is repeated for all lines. When all lines have been processed from the top to the bottom, the same procedure is repeated from the bottom to the top. The result will then be a raster file containing the values 0 = outside a polygon, 1 = inside a polygon and 2 = a polygon boundary pixel.

Vector data representing a continuous, in a mathematical sense, variable may be converted to raster data either through interpolation or surface-fitting techniques. Interpolation algorithms are described in e.g. Shephard (1984) and Monmonier (1982). Surface-fitting is another efficient way of transferring point data to continuous raster data. Please refer to e.g.

Agterberg (1984) for a review of different trend surface analysis approaches. See also Chapter 8.

Description and computer programmes for both interpolation and surface-fitting can be found in e.g. NAG Library (NAG 1984) and UNIRAS (ESC 1984).

Thematic information layers can be transferred into vector form through raster-to-vector conversion. The method used here transfers a thematic information layer into a data-vector containing the addresses of the boundary pixels only. The reason for this can be to save storage space or that the boundaries of an information layer are needed.

The method is straightforward. The raster is searched to find a pixel belonging to the polygon. If this pixel has any non-polygon pixels as orthogonal neighbours, it is a boundary pixel and the addresses will be stored, otherwise it is not a boundary pixel, see Fig 5.4.

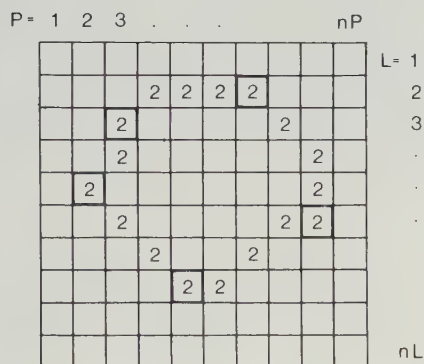


Fig. 5.4. The principle of the raster-to-vector conversion.

4. DATA MANIPULATION AND ANALYSIS

A number of statistical techniques can be applied to combine different types of data in a GIS. The choice of methodology must depend on the nature of both the existing data, i.e. the input variables, and the new data that shall be created. The scheme in Fig. 5.5 gives some examples of appropriate techniques.

Analysis of relationships between different information layers as well as within the different information layers can efficiently be carried out by analysis of variance and correlation methods. The use of thematic information layers as masks in statistical analysis is very useful.

		INPUT		
		Continuous	Mixed	Categorical
OUTPUT	Continuous	Regression Models - linear - curvilinear	Analysis of Covariance Multivariate Analysis of Covariance Regression Under Mask	Analysis of Variance Multivariate Analysis of Variance
	Categorical	Maximum Likelihood Classification Logit Modeling Discriminant Analysis	Maximum Likelihood Classification with Prior Probabilities Maximum Likelihood Classification using Masks for Exclusion of Areas Maximum Likelihood Classification with Different Training-Statistics under Masks Logit Modeling	Contingency Table Analysis Logit Modeling

Fig. 5.5. Some statistical techniques for combination of information layers of different type. Modified from Wrigley (1979) and Strahler et. al. (1980)

5. Data Presentation

The most common form of presentation of remote sensing data is in image form for continuous information (e.g. biomass) or map form for categorical information (e.g. classified data). Presentation of data in a GIS in tabular or diagram form is however often desired. The combination of software for remote sensing analysis, for handling of spatial data in other than image form (GIS - software) and appropriate graphical software for raster as well as vector presentation is necessary.

six

Spatial Models of Land Use

1. INTRODUCTION

In a geographical information system we have statistical methods for analysis and combination of data in both raster and vector form. The term spatial models have been used here for different methods to transform point or line data into continuous raster data. In some of the models, a priori knowledge of the spatial influence of these data can be included.

The reason why these techniques are needed, is that a large amount of data on human features of the landscape are, in a spatial sense, not continuous but confined to a point or line. These landscape features does however influence the surroundings. In order to describe these influences, other types of methods than the conventional ones are needed.

In the middle of the nineteenth century the term social physics was used in attempts to find analogies between the physical laws and the behaviour of human societies. The idea of population potential and gravity emanated from the work by H.C. Carey

"Man tends of necessity to gravitate towards his fellow-man. Of all animals he is the most gregarious, and the greater the number collected in a given space the greater is the attractive force there exerted, as is seen to have been the case with the great cities of the ancient world, Nineveh and Babylon, Athens and Rome, and as is now seen in regard to Paris and London, Vienna and Naples, Philadelphia, New York, and Boston. Gravitation is here, as everywhere in the material world, in the direct ratio of the mass, and in the inverse one of the distance." (Carey 1858-1865, Vol I, p. 43)

During the 1940s and 1950s the astronomer J.Q. Stewart (e.g. 1941, 1947 and 1958) adopted physical laws to the study of societies. This was thought to become a cornerstone of a new macrogeography (Rich 1980). However, the use of these models in geography is presently rather limited.

In this thesis I have taken up some of the ideas from the works related to "social physics" in order to develop methods of transformation of point data to continuous raster data. Several

models have been developed. In chapters 8 and 9, they will subsequently, be reviewed and tested through comparison with remote sensing data.

2. POTENTIAL MODELS

The potential model is a fairly well-known concept in geography, what is new is probably the application on land degradation and combination with remote sensing data in a geographical information system.

The concepts of force and energy in Newton's law of gravity was further developed by Lagrange (1788) by adding the concept of gravitational potential. The total gravitational potential could then be defined as:

$$V_i = (m_j / d_{ij})$$

where V_i = the total gravitational potential at mass i

m_j = mass j

d_{ij} = distance between mass i and j

In analogy with this, e.g. population centres, can be treated as the masses to calculate the population potential. In geography it is however not necessary to follow the physical law and use exponent 1 of the distance. A discussion of different values of the distance exponent can be found in Rich (1980).

In order to use the concept of potential model to create continuous information in raster format the potential at any given point can be defined as shown in Fig. 6.1.

Different kinds of land use exert different types of influence on the surrounding environment. Grazing of domestic animals is an example of a land use type that is spatially very flexible. Cultivation can serve as an example of a land use type that is spatially much more restricted. A potential model can be modified to best fit a certain type of activities, in two ways. The number of neighbouring points taken into consideration in the calculation can be varied, and the distance weight can be varied in order to control the balance between proximity of a point and the magnitude (e.g. number of inhabitants) of it.

The algorithm developed for construction of potential models from point data is described in the following steps.

1. The point data, in the form of coordinate triplets (x , y and z coordinates) are sorted into the raster system. For simplicity, these grid cells will be called points.
2. A search order is generated. The euclidian distances between a center point and all grid cells in one quadrant are computed and stored in an array as x , y and z coordinates. This vector is then sorted with respect to the z -coordinate, i.e. the euclidian distance. Usually a maximum distance is set depending on the type of land use under consideration.

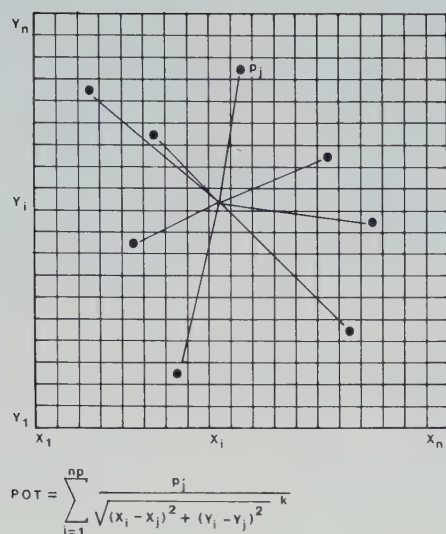


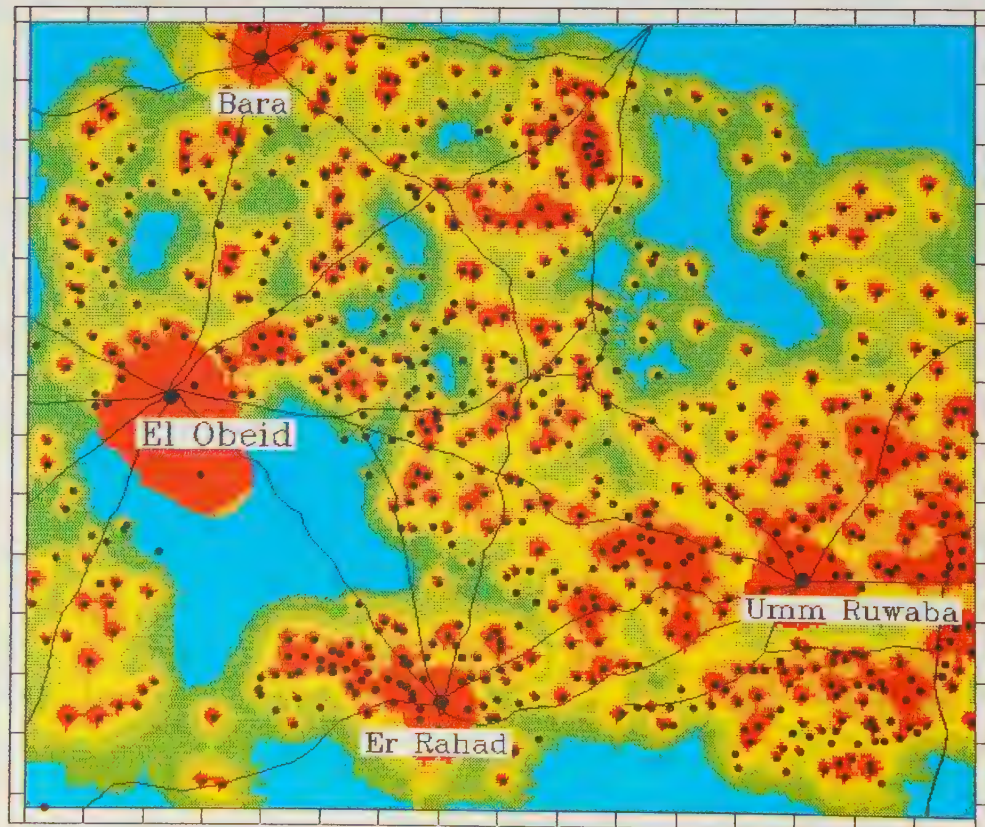
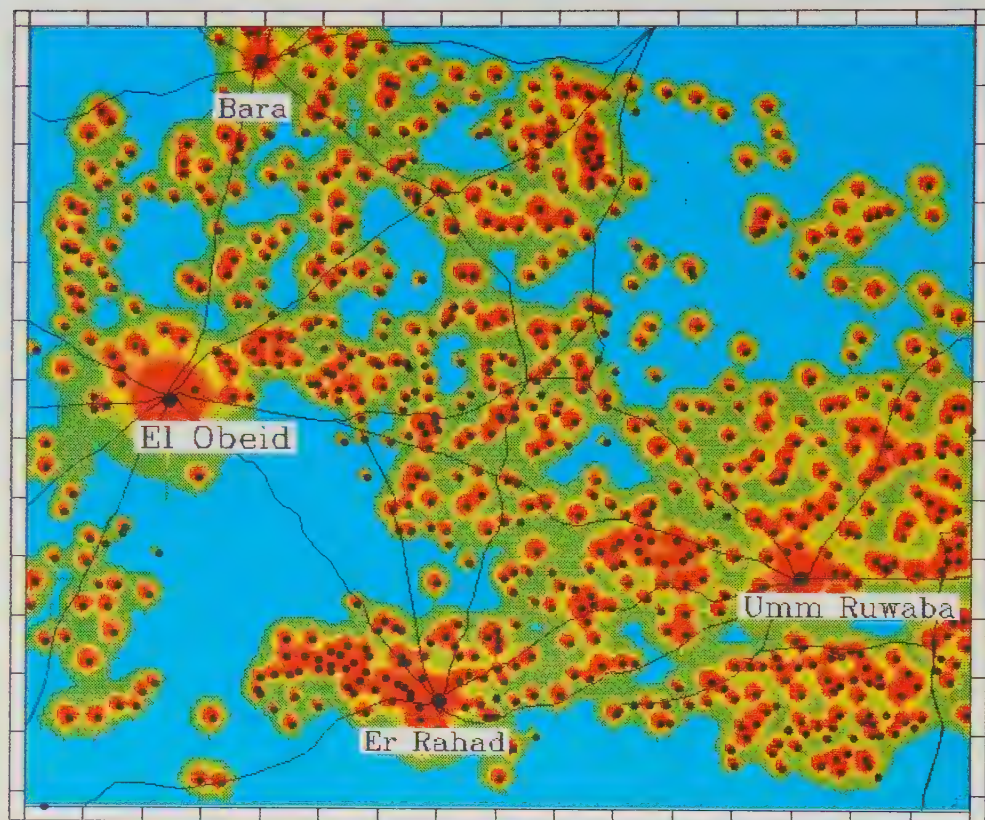
Fig. 6.1. The principle of potential calculation in a raster.

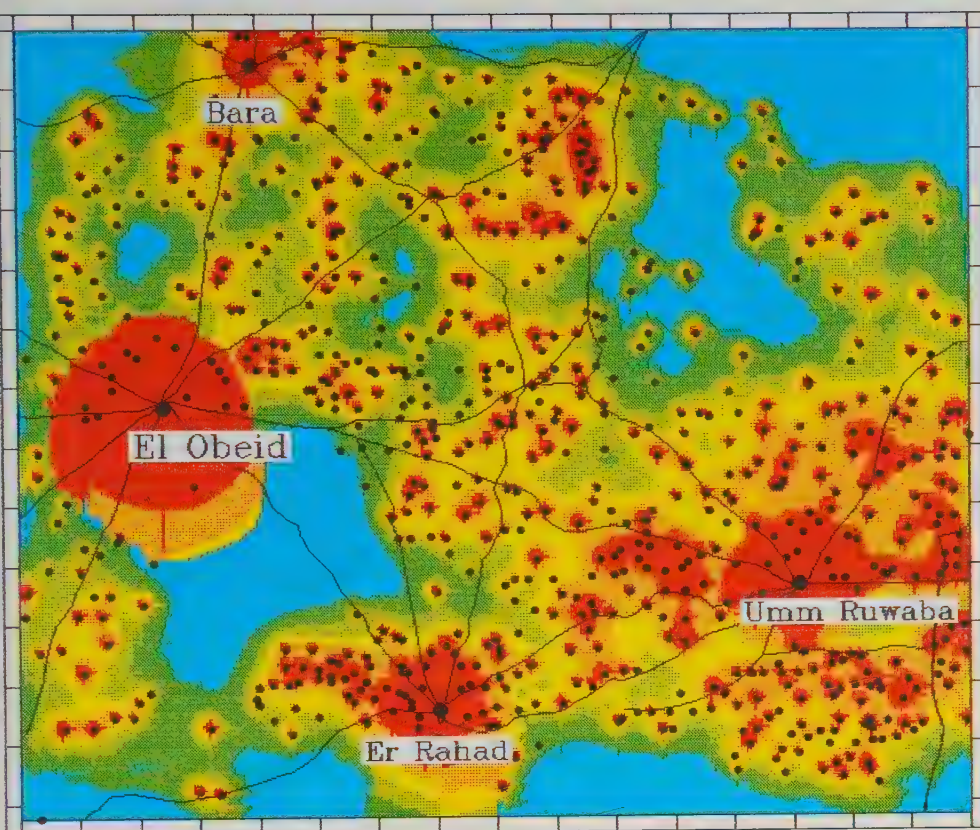
POT = the potential at gridcell x_i, y_i
 p_j = the population in the point j
 x_i, y_i = the coordinates of gridcell i
 x_j, y_j = the coordinates of point j
 k = distance factor (empirical)

3. For every grid cell in the raster a search is then carried out for the nearest neighbouring points in four quadrants, using the x and y coordinates of the search array. The number of neighbouring points can be chosen arbitrarily.
4. Once the desired number of neighbouring points have been found, the potential of the grid cell can be calculated according to the formula in Fig. 6.1. Since the distances between the grid cell and the points are already known from the z -value in the search array, the calculation of potential is straightforward.
5. The steps 3 and 4 are then repeated for all grid cells in the raster.

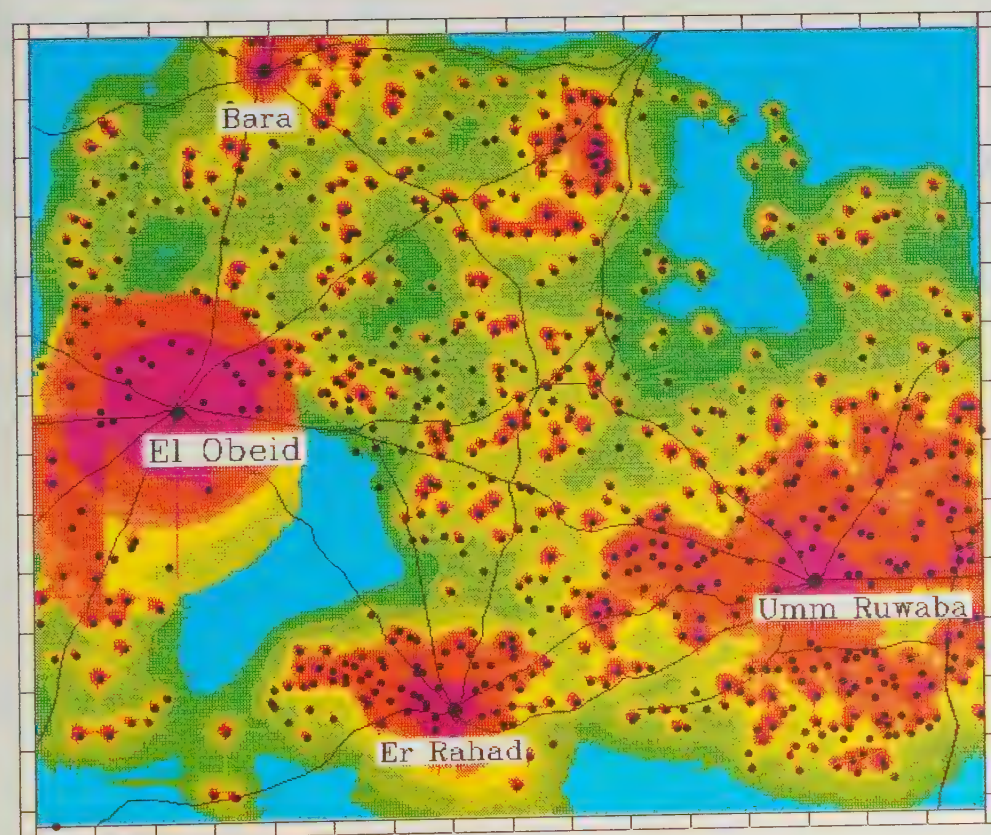
In Figs. 6.2, 6.3, 6.4 and 6.5 population potential maps are presented with different number of neighbouring points considered and with different weights on the distance factor. We can see how the spatial influence of the population centres can be controlled by both the distance exponent and the number of points included in the potential calculation.

In a real landscape the situation is much more complicated than can be simulated in a mathematical model. One type of limitation of land use are barriers in the landscape. Mountains,





6.4



6.5

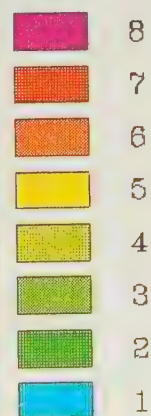


Fig. 6.2. Potential model based on data from the village map presented in Fig. 4.37. Number of neighbours = 10, distance factor = 3. The colour scale corresponds to: 1 = 0 - 20, 2 = 20 - 40, 3 = 40 - 60, 4 = 60 - 80, 5 = 80 - 100, 6 = over 100.

Fig. 6.3. Potential model based on data from the village map presented in Fig. 4.37. Number of neighbours = 25, distance factor = 3. The colour scale corresponds to: 1 = 0 - 20, 2 = 20 - 40, 3 = 40 - 60, 4 = 60 - 80, 5 = 80 - 100, 6 = over 100.

Fig. 6.4. Potential model based on data from the village map presented in Fig. 4.37. Number of neighbours = 25, distance factor = 1.5. The colour scale corresponds to: 1 = 0 - 20, 2 = 20 - 40, 3 = 40 - 60, 4 = 60 - 80, 5 = 80 - 100, 6 = over 100.

Fig. 6.5. Potential model based on data from the village map presented in Fig. 4.37. Number of neighbours = 50, distance factor = 1.5. The colour scale corresponds to: 1 = 0 - 20, 2 = 20 - 40, 3 = 40 - 60, 4 = 60 - 80, 5 = 80 - 100, 6 = 100 - 120, 7 = over 140.

Scale: Interval between tickmarks correspond to 10 km.

rivers, administrative and tribal boundaries can restrict the spatial pattern of land use. In the algorithm described above linear barriers can be treated and different regions can be handled separately.

A linear barrier is e.g. a river or a mountain ridge. Information on barriers can be taken from the GIS, superimposed on the raster system and used in the algorithm. In the third step above, it is possible to test whether there is a barrier between the grid cell and the point. This is done by establishing the equation of a straight line between the grid cell and the point. If there are any boundaries along this line, the point must be rejected as a neighbour to the grid cell.

The raster in which the potential calculations are carried out can be added information from the GIS on e.g. tribal or administrative boundaries. The potential calculation can then be carried out separately for each region.

The points can be given different priorities or be weighted. If potential calculation is made on e.g. availability of ground water, the wells can be differentiated depending on the quality of the water. Water in a well may be drinkable for livestock only, therefore we will get different "water potentials" for livestock and for people.

In Fig. 8.10 the water potential map is presented, based on all wells. As most of the wells lacked information on water quality, it was impossible to generate separate maps.

Since the potential is not a tangible concept, like e.g. density or distance, much research and field work is necessary

to be able to correctly estimate the values of the two variables involved, i.e. number of points and the distance factor. Different types of land use and data require different values of the variables to yield an adequate result.

3. EQUIDISTANCE MODEL

Many problems in connection with utilisation of natural resources in arid and semi-arid regions can be related to a question of distance to different landscape features. One example is the utilisation of range resources, which is very much dependent on the availability of drinking water. Different animal species have different water requirement i.e. the importance of distance to the nearest well varies with species.

A more subtle effect of distance may be on the disposition to economic and social changes. It can be assumed that villages near a main market town or near a main communication link are more inclined to adapt new ideas and methods. As an example, we can assume that inhabitants in a village near a main market are more inclined to grow sesame and ground nuts (cash crops) than inhabitants in a more remote village. The cultivation of these crops is often assumed to be more risky than millet cultivation, because they are not as drought resistant as millet.

An equidistance model can be used for generating thematic maps or information layers describing the distance to the nearest point where a certain facility can be found, e.g. well, village, market or road. Integrated in a GIS it can provide explanatory information to be used in the analysis of relationships between different environmental parameters. It is also a valuable complement to other thematic information.

Two different procedures can be used for the generation of equidistance maps. The first is the same as steps one to three in the potential model. The grid cell will be given the value of the distance between the grid cell and the first neighbour found. This procedure is followed to produce a full-covering map, where every pixel will be given a distance value. If only a limited distance region is considered, the point itself is the starting point. The pixels around the point are given distance values up to a given maximum distance. Fig. 6.7 is a continuous map showing the distance to the nearest village.

4. SPATIAL DIFFUSION MODELS (HEXAGONALITY MODELS)

Spatial patterns of points can be of three fundamentally different types: random, clustered or uniform, see Fig. 6.8. The idea behind analysis of spatial patterns in geography as well as other disciplines is that different processes give rise to different spatial patterns.

Uniform patterns are assumed to be caused by competition for e.g. space between adjacent points. A good example of this is

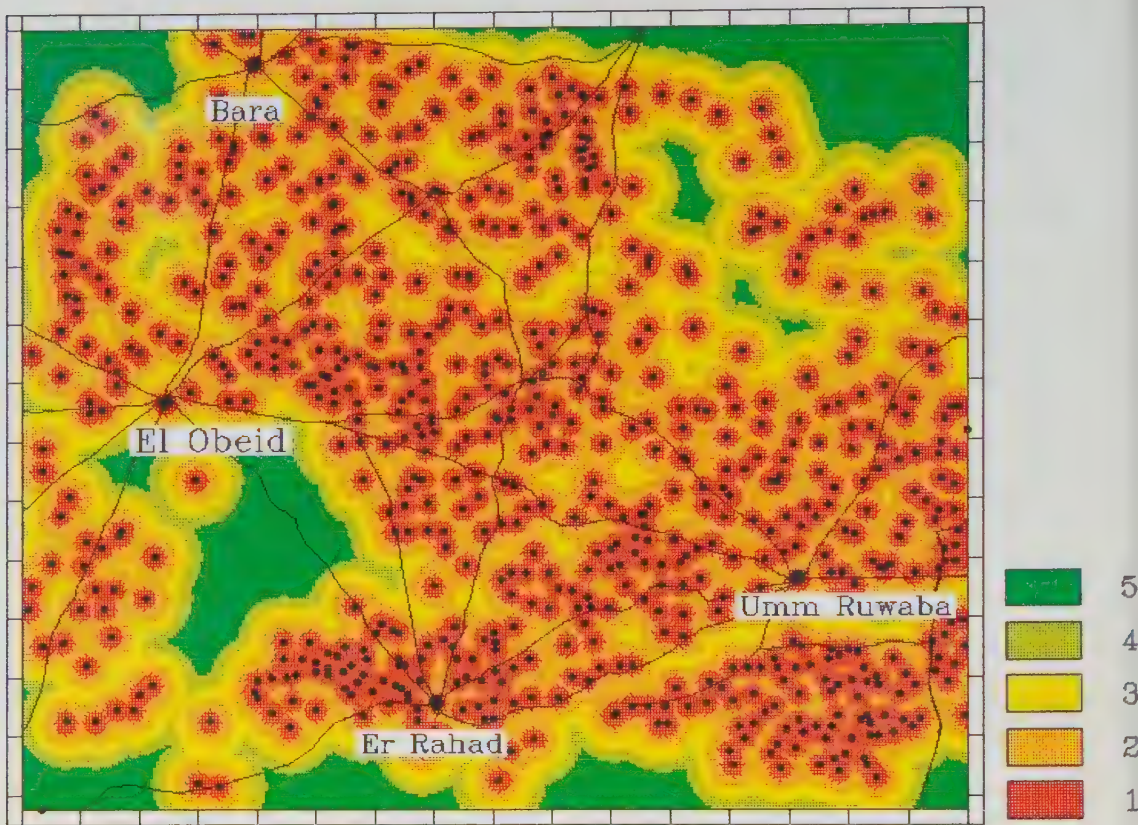


Fig. 6.7. Map showing distance to nearest village with no barriers in the landscape and no division into regions. The colour scale corresponds to: 1 = 0 - 2 km, 2 = 2 - 4 km, 3 = 4 - 6 km, 4 = 6 - 8 km and 5 = over 8 km.

the competition for agricultural land between villages. The cultivated fields are located as close to the village as possible. The triangular pattern is the ultimate uniform pattern, where the distance between points is maximized.

Clustered patterns are supposed to be generated by contagious processes. This means that a location of one point attracts subsequent point locations to the vicinity. Two such processes may be important in the study area, the availability of a well with access to ground water of good quality, and the presence of a market.

A random spatial pattern is assumed to be the result of an independent stochastic process, i.e. there is no special preference to a certain locality. It may also indicate uniform land conditions, i.e. the resources are equally distributed over the area and there is no competition for space.

The study of spatial patterns of settlements is one of the cornerstones of human geography. Bunge (1962) puts it in the

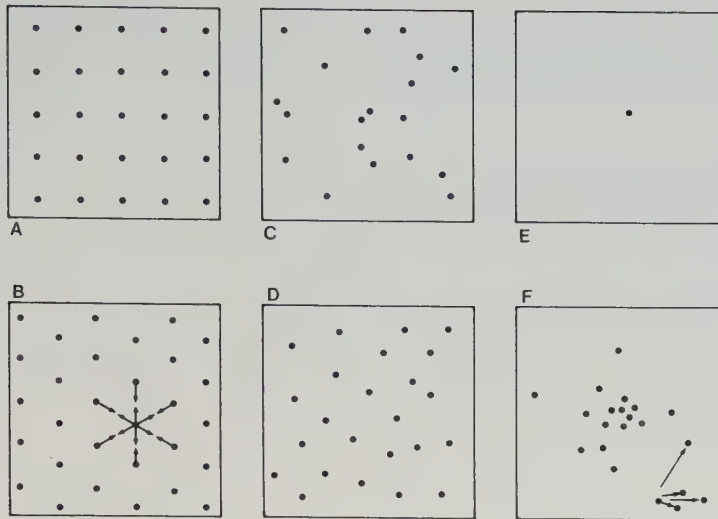


Fig. 6.8. The continuum of spatial patterns, from uniform (A and B), over random (C and D) to clustered (E and F). From Thomas & Huggett (1980)

following way: "With the possible exception of cartography the initial and growing beauty of central place theory is geography's finest intellectual product and puts Christaller in a place of great honor."

Christaller assumed a uniform hexagonal pattern of settlements rather than a square pattern, see Fig. 6.9. According to Bunge (1962), "He deduces that with the given uniform distribution, a hexagonal market area requires the least average distance of movement to the centers for consumers". This means that the basic assumption behind the uniform pattern is the central place, i.e. a common resource.

For the studies of spatial pattern of villages in this chapter I have assumed two antagonistical spatial processes generating the patterns. These are:

1. Competition for land, acting as a generator of a uniform, hexagonal pattern,
2. Desire to minimize the distance to a common resource or facility, e.g. ground water supply or market acting as a generator of a clustered pattern.

In order to reveal the geographical forces behind a certain spatial pattern some methods of spatial point pattern analysis can be carried out. Several methods exist. Most of them have in common that they have originally been developed for treatment of biological or ecological data. Many methods have however been applied to geographical studies, mostly in human geography.

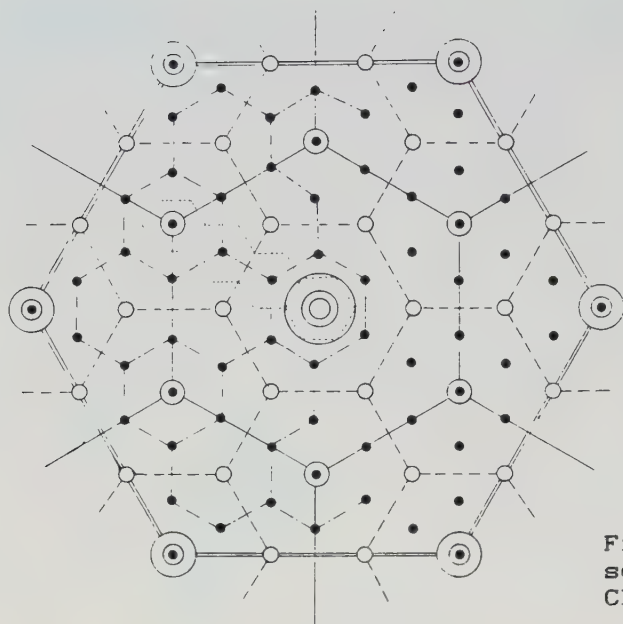


Fig. 6.9. Arrangement of settlements according to Christaller (King 1984).

The two most commonly used methods of analysis of point patterns are nearest neighbour statistics and quadrat analysis. Nearest neighbour analysis is based on the frequency distribution between dyads of nearest points. According to Thomas and Hugett (1980) and King (1969), the nearest neighbour analysis has too many theoretical and practical problems to be considered as a reliable method of point pattern analysis. Its principal drawback comes from the geographical boundary value problem (Griffith 1984).

Quadrat analysis is a family of methods for analysis of spatial point patterns. Quadrat analysis methods use probability theory for investigating and modelling of the frequency distribution of spatial point patterns. The generator of the point patterns is often assumed to follow the Poisson distribution.

Methods of quadrat analysis are comprehensively treated in Greig-Smith (1983) and Thomas (1977).

The quadrat analysis has a number of drawbacks which restrict the utility of the method, especially in combination with cartography.

1. The analysis is very much dependent on the size of the region within which the analysis is carried out. The result may be severely biased by the choice of geographical region.
2. The scale at which the analysis is carried out influences the result very much. Depending on the size of the cells used, diametrical results can be achieved.

3. The result is one measure describing the whole point population. It is impossible to use quadrat analysis for generation of spatially continuous information

The use of remote sensing for analysis of settlement pattern was demonstrated by Lo (1984) for two areas in China. Radar data (SIR-A) were used to detect settlement. Quadrat analysis and nearest neighbour analysis were used to investigate the type of spatial distribution. A regular (Christaller type) spatial structure was not found. The article was criticised by Flowerdew (1984): "The analysis, which contains some technical errors, allows him to support or reject only extremely implausible theories about the settlement process", "...his statistical tests do little beyond disproving (or supporting, as he claims) a theory of settlement that nobody believes anyway".

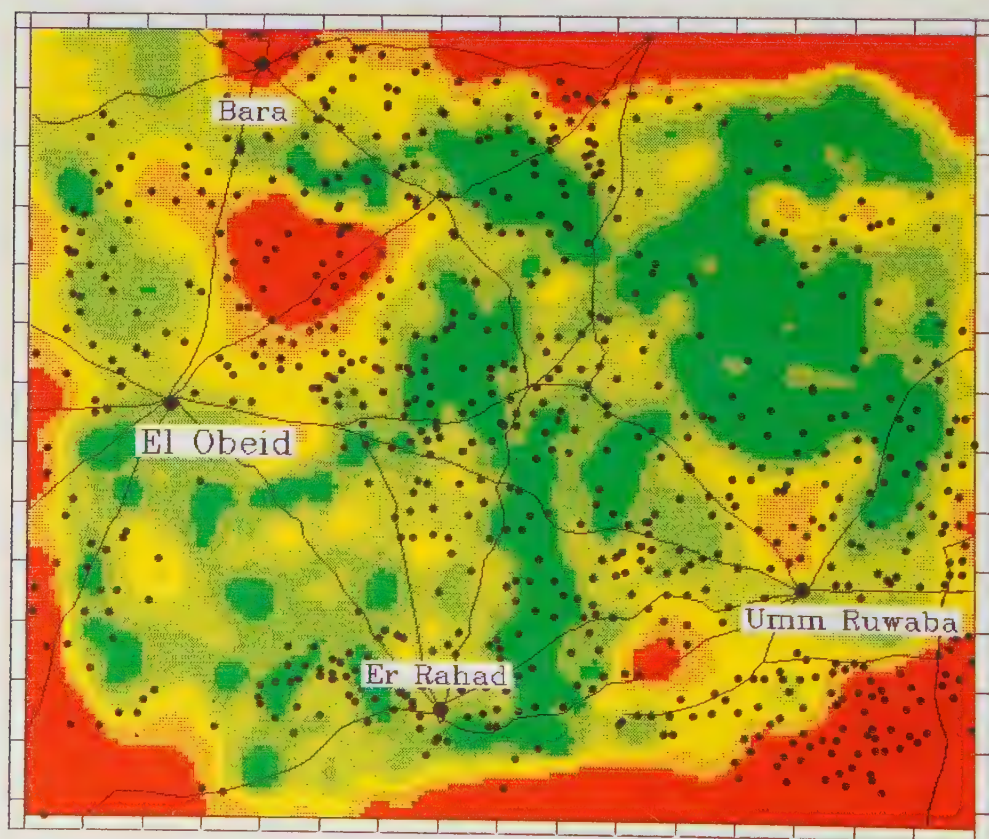
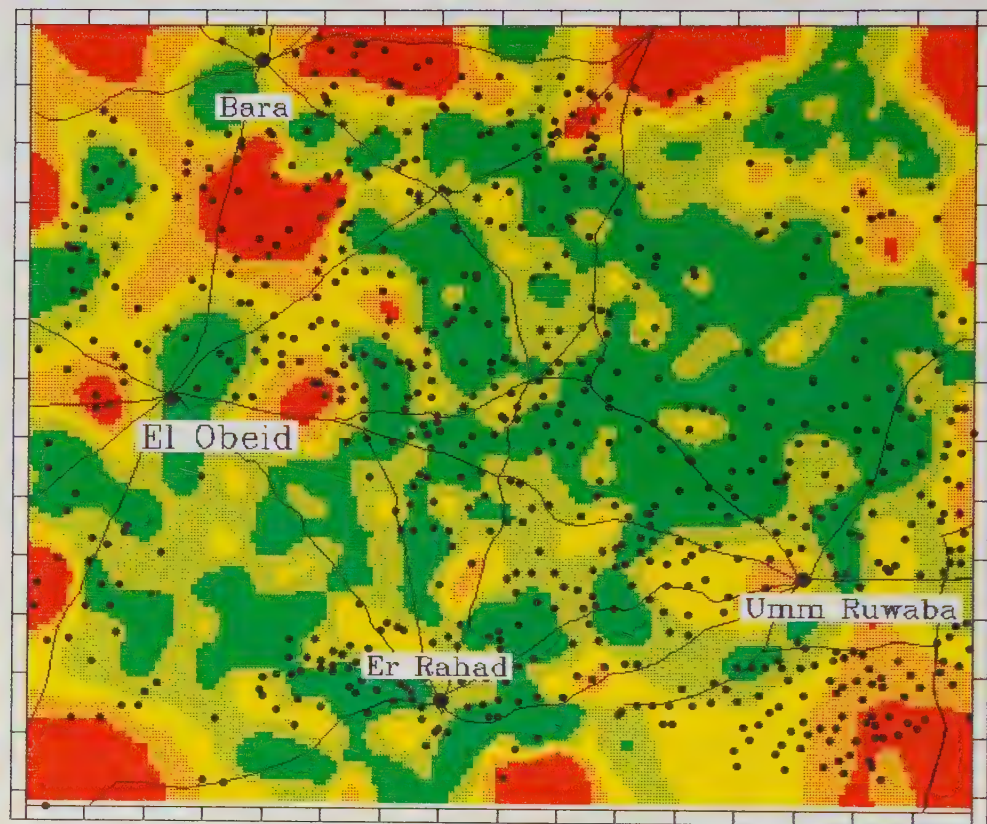
An interesting approach to analysing point patterns with possibilities of detecting degree of hexagonality was presented by Bunge (1962). A severe drawback is however that it involves rather tedious moments of manual preprocessing, which makes it less useful in analysis of large quantities of data.

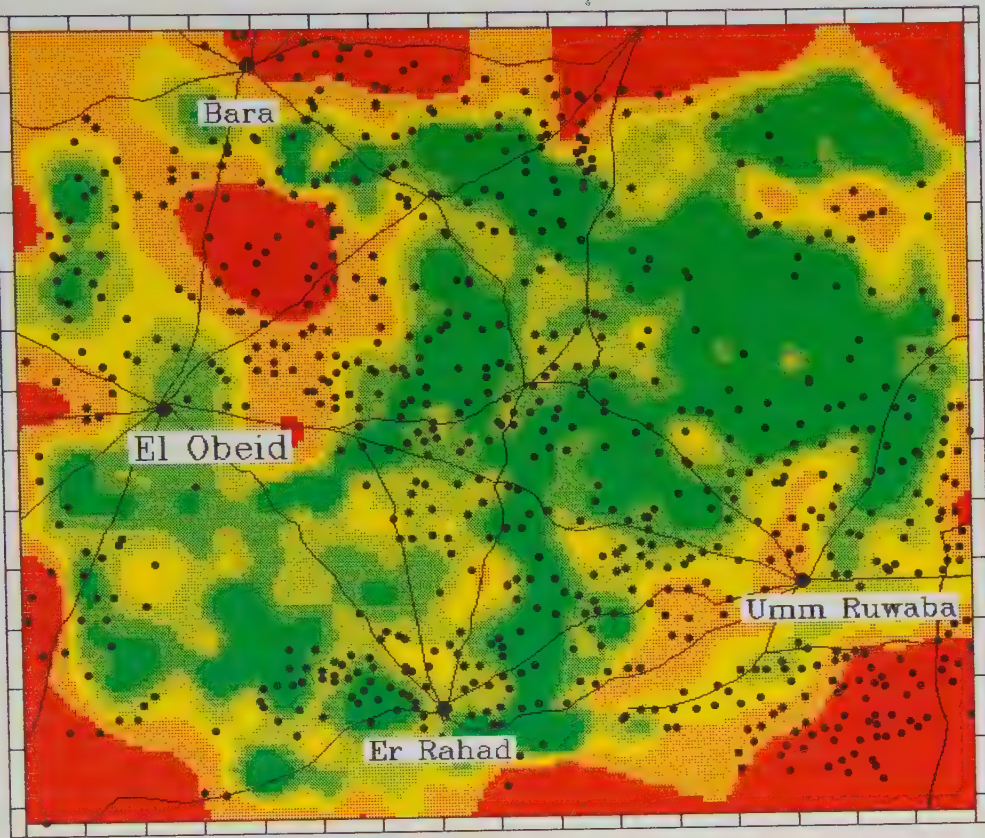
The rationality behind the investigation of spatial patterns in this thesis is that the spatial arrangement of villages and towns may be of importance for land degradation. However, it is then necessary to assume equally distributed resources. In areas where the villages are arranged in a hexagonal pattern there is no space for expansion of a cultivated area when the population increases and when low rainfall causes a severe decline in crop yield. Hellden (1984) demonstrated the significant increase in cultivated area during the Sahelian drought, 1968 - 1974, and the following decrease in cultivated area after the drought.

In order to avoid the limitations of quadrat analysis and to measure the degree of hexagonality a spatial index, hexagonality index I_h , was developed by the author in cooperation with Mikael Stern.

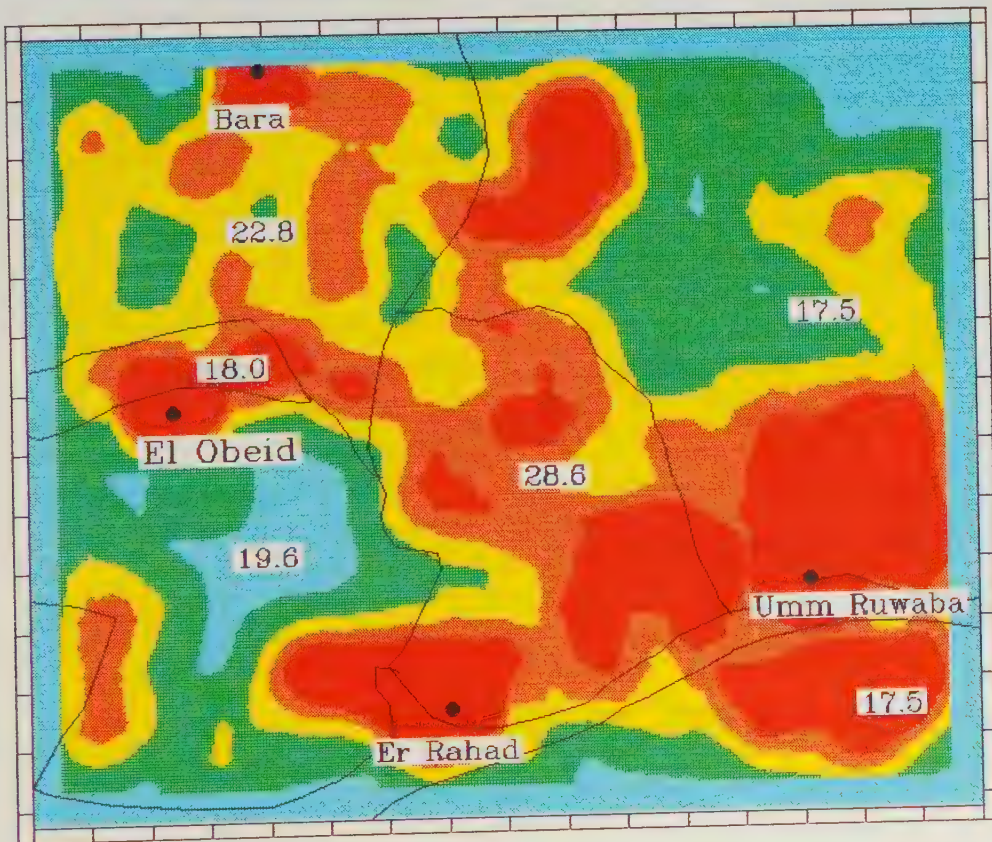
The hexagonality index measures the degree of hexagonality of every point in a point pattern. The method is more straightforward than the method suggested by Bunge (1962), and can be fully automatized in a computer. The following scheme describes the procedure, see also Fig. 6.10.

1. The index is successively calculated for each point, P_i , in the whole population. The coordinates of the points $P_1 - P_n$ are transformed into polar coordinates with reference to the point under consideration (P_c).
2. The area around P_c is searched for the nearest neighbour in sectors of 80 degrees.
3. The six nearest points in these sectors are selected as neighbours. The coefficient of variation of the distances, CVD , and the angle differences, CVa , are calculated.





6.13



6.14



Fig. 6.11. Hexagonality index, distance, of the village map presented in Fig. 4.37. The colour scale corresponds to: 1 = 0 - .25, 2 = .25 - .30, 3 = .30 - .35, 4 = .35 - .40 and 5 = over .40.

Fig. 6.12. Hexagonality index, angle, of the village map presented in Fig. 4.37. The colour scale corresponds to: 1 = 0 - .35, 2 = .35 - .40, 3 = .40 - .45, 4 = .45 - .50, 5 = .50 - .55 and 6 = over .55.

Fig. 6.13. Hexagonality index, combined, of the village map presented in Fig. 4.37. The colour scale corresponds to: 1 = 0 - .30, 2 = .30 - .33, 3 = .33 - .36, 4 = .36 - .39, 5 = .39 - .45 and 6 = over .45.

Fig. 6.14. Population density, summed over 110 sqkm areas, and presented as number of inhabitants per sqkm. The boundaries of ecotypes and the number of inhabitants per sqkm according to Watson et. al. (1976) are indicated. The colour scale corresponds to: 1 = uninhabited, 2 = 0 - 10 inh/sqkm, 3 = 10 - 20 inh/sqkm, 4 = 20 - 30 inh/sqkm and 5 = over 30 inh/sqkm.

Scale: Interval between tickmarks correspond to 10 km.

4. A distance index and an angle index are calculated,

$$Id = \frac{1}{(1-CVd)}$$

$$Ia = \frac{1}{(1-CVa)}$$

These two indices, varying from 0 to 1, describe the variation in distance to the neighbours as well as the angular distribution of the neighbours in relation to the center, P_c .

The combined hexagonality index can finally be calculated,

$$Ih = \frac{(Id + Ia)}{2}$$

This index varies between 0 and 1, where 1 denotes that the P_c point is the center of a perfect hexagon. The whole procedure is repeated for all the points in the pattern.

Continuous information can subsequently be generated by interpolation of the hexagonality index of every point. It is then desirable to interpolate with a high degree of smoothing.

A modified version of the hexagonality index algorithm measures not only the variation in spatial arrangement of the point

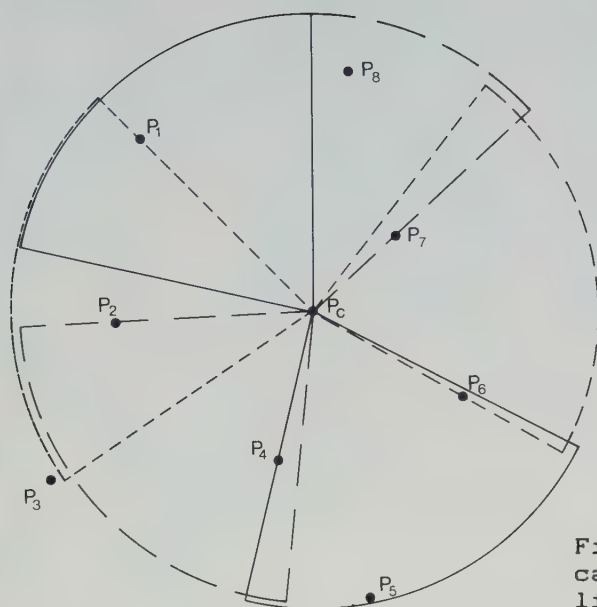


Fig. 6.10. The principle of calculation of the hexagonality indices.

pattern, but also the variation in the values of the points. Figs. 6.11 - 6.13 show the different hexagonality indices.

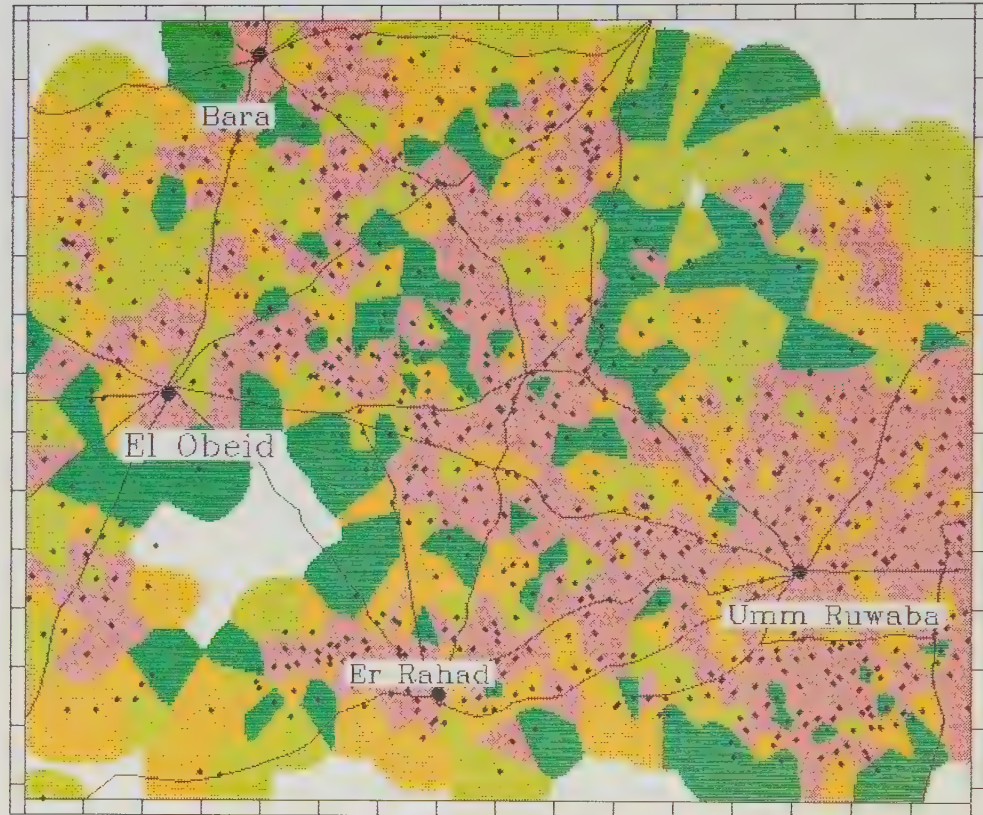
We can see from the hexagonality images, that the spatial arrangement of villages varies substantially over the study area. Two spots of high degree of hexagonality can be found, between El Obeid and Bara, and south of Umm Ruwaba. The latter area was expected to show high values of hexagonality, since the villages are very densely distributed over the area. Otherwise it is difficult to find any clear evidences for the theory of a hexagonal pattern of villages in the most densely populated regions, where the competition for land is supposed to be strong.

5. POPULATION DENSITY MAPPING

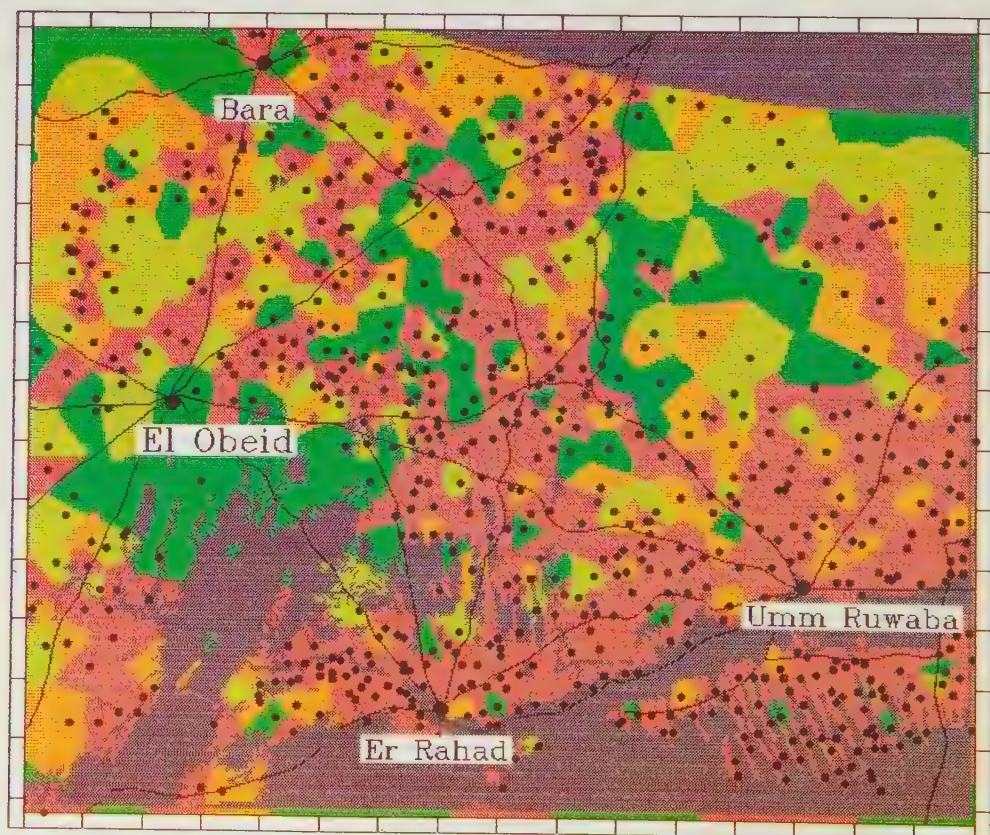
Population density is a commonly used parameter. It is, however, often calculated over administrative (e.g. census) districts resulting in very rough figures, insensitive to local variations. Another way of calculating population density is to use spatial filtering in analogy with filtering of image data.

The population centres (digitized as x , y and z = inhabitants) are transferred to a regular grid net. Spatial filters of variable sizes can then be used to calculate the number of inhabitants per area unit. The sum of all village populations within a filter is divided by the filter size to give the inhabitants/area unit.

The advantage of this type of population map is that the concept of population density becomes more tangible than the

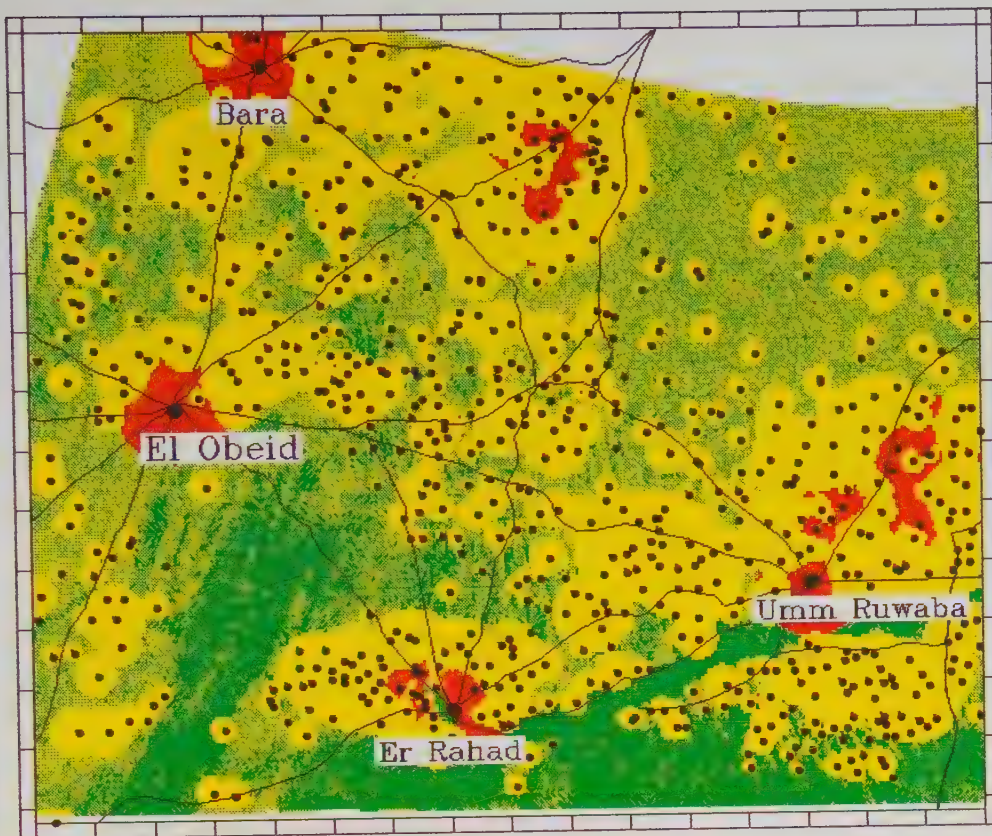


6.15

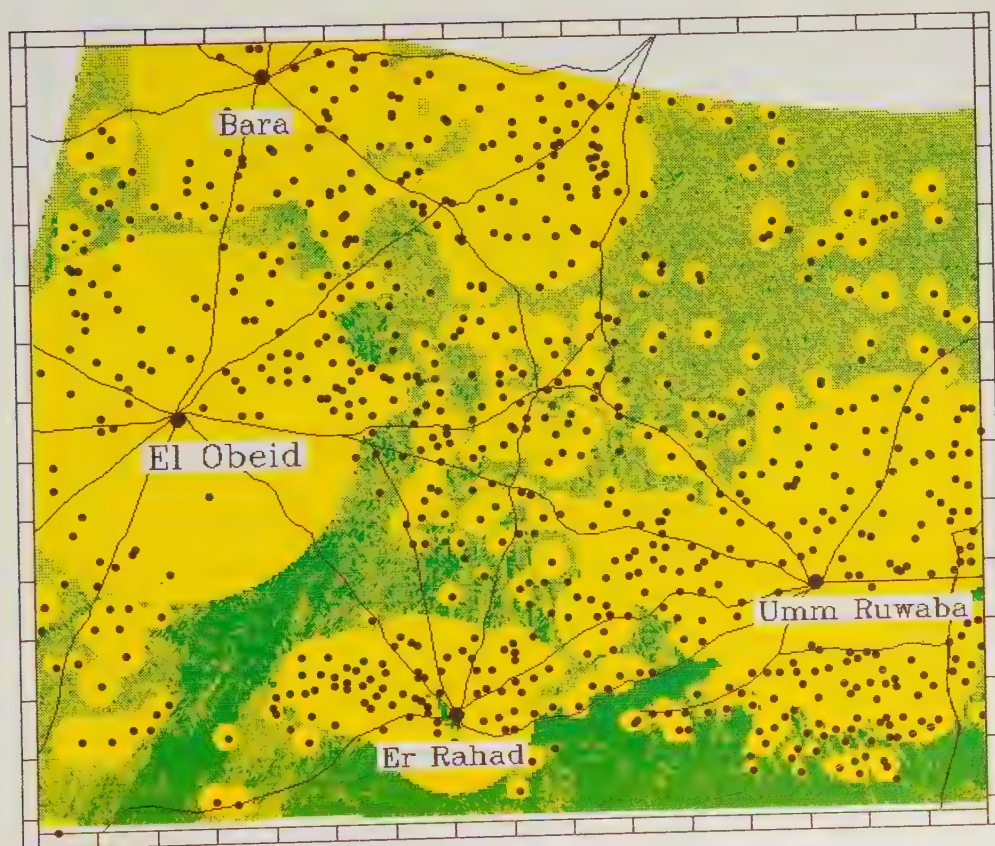
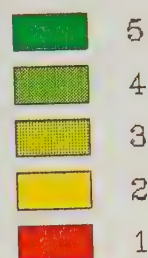


6.16





6.17



6.18



Fig. 6.15. Land availability map showing the number of hectares per capita within a 10 km circle from the village. No ancillary information on soil conditions is included. The colour scale corresponds to: 1 = below 5 ha/cap., 2 = 5 - 10 ha/cap., 3 = 10 - 20 ha/cap., 4 = over 20 ha/cap. and 5 = uninhabited areas.

Fig. 6.16. Land availability map, same as shown in Fig. 6.15, but with fine-textured soil excluded. The colour scale corresponds to: 1 = below 5 ha/cap., 2 = 5 - 10 ha/cap., 3 = 10 - 20 ha/cap., 4 = over 20 ha/cap. and 5 = soil mask and uninhabited areas.

Fig. 6.17. Combined production/demand map of woody biomass. Maximum travel distance was set to 10 km (from Olsson et. al. 1985). The colour scale corresponds to: 1 = deficit areas, 2 = areas with balance between supply and demand, 3 = surplus 0 - 10 tons/ha, 4 = surplus 10 - 20 tons/ha and 5 = surplus over 20 tons/ha.

Fig. 6.18. Combined production/demand map of woody biomass. Infinite travel distance was assumed (from Olsson et. al. 1985). The colour scale corresponds to: 1 = areas with balance between supply and demand, 2 = surplus 0 - 10 tons/ha, 3 = surplus 10 - 20 tons/ha and 4 = surplus over 20 tons/ha.

Scale: Interval between tickmarks correspond to 10 km.

potential model, without losing the spatial resolution, as is the case with conventional density mapping. In Fig. 6.14, a comparison can be seen between a conventional population density map (from Watson et. al. 1976) and a population density model as described above. The population density map is also presented as a 3-D map on the cover. The use of population density, measured by administrative regions, or as in the case of Watson et. al. (1976), by ecological regions, is very misleading. The approach may be justified if applied over very large areas, e.g. at a regional or a continental scale.

6. LAND AVAILABILITY MODEL

Shortening of fallow periods in traditional rain-fed cultivation is often considered as an important factor leading to desertification. According to Hammer-Digernes (1977), the fallow periods in the Bara region have dropped from 17 to 8 - 12 years. Olsson K. (1984b) summarized several sources and concluded that the fallow periods have generally been shortened. However, the pattern varies considerably in time and space in Northern Kordofan and can hardly be used as an indicator of desertification (Hellden 1984). One obvious reason for shortening fallow periods is that shortage of land forces the people to cultivate the available land more intensively.

In order to investigate the pattern of possible cultivation/fallow cycles in the study area, a methodology for calculation of land availability was developed. It is based on the village populations estimated in Chapter 4, and presented in Fig. 4.34.

The following steps are carried out.

1. The data (x,y and z coordinates) are sorted into the grid system and a search order is generated according to steps 1 and 2 in the potential model (Section 2). Every grid cell is given a value equal to the size of the cell in e.g. hectares or square kilometres.
2. Starting from each village, the number of pixels, i.e. the area of land, within a certain maximum distance, are added spiralwise according to the search array. The pixels are given the negative value of the village index.
3. If a pixel less than zero is found, it means that it has already been ascribed to another village. The algorithm tests whether the pixel is closer to the new village or not. If that is the case, the pixel will change value to the new negative village index.
4. The sums of all pixels belonging to the respective villages are stored in a table. When the whole image has been processed the pixels will be given the value corresponding to the number of hectares per capita in the respective village. The table will also be presented on a separate file. Instead of giving the pixels the value in hectares per capita it is easy to transform the data to theoretical fallow periods, given a fixed cultivation period, see Fig. 8.3.

Linear barriers can be treated as described under the potential models. In the algorithm it is also possible to include information on soil type from a digital soil map in order to exclude agricultural impediments in the map generation. This information is easily included as pixels with the value of zero after the first step. No other modifications are needed. In Fig. 6.15, the land availability map showing hectares per capita without any agricultural impediments considered, is shown. In Fig. 6.16. the same map with the fine textured soils excluded is shown.

7. A COMBINED SUPPLY/DEMAND MODEL

The ultimate step of resource monitoring must be the study of the balance between supply and demand of a given natural resource. Remote sensing is a frequently used tool for resource mapping. The most common way of expressing population density, e.g. per administrative unit or as Watson et. al. (1977) per ecological unit, is however inadequate for studies of supply/demand in other than very small scales (e.g. at a national scale). The map in Fig. 6.14, accounts for the population density as calculated by the population density model (section 6.5) superimposed by the population densities presented by Watson et. al (1976).

In order to study the spatial pattern of supply and demand more accurately, a combined supply/demand model was developed. It is a development of the land availability model. Instead of only adding the amount of land (i.e. number of pixels) around each village, this model takes the pixel values of a resource map into consideration. If an absolute calibration of pixel values to e.g. biomass can be established and the per capita demand of this resource can be estimated, this is a very efficient way of generating data on the spatial pattern of the balance between supply and demand.

The extra information gained from this model compared with the land availability one is that the table data for each village will contain either the eventual deficit found or the travel distance needed to satisfy the demand.

With a supply image as input to the land availability model, together with a table of village coordinates and the demand of the resource under consideration, the resulting image will show three kinds of information,

1. the original supply data in regions where there was no demand
2. zero values in areas where the supply was greater than the demand
3. negative values indicating the actual deficit that arose within the given maximum distance.

One application of this model on supply and demand of fuel wood was presented by Olsson et. al. (1985). The yearly demand for wood per capita was estimated from interviews at 1000 kg. The total demand per village was calculated and combined with a woody biomass map (where the pixel values corresponded to tons/pixel), generated from a Landsat MSS ratio. See further Olsson K. (1984b and 1985) for details on the estimation of woody biomass. The annual production of woody biomass was estimated to 7 % of the standing stock, and the supply image was consequently transformed into an image showing the yearly production of woody biomass. The area around each village was searched and the supply of woody biomass was added. A maximum distance from village center was set to 10 km in a first model performance, the resulting map is shown in Fig. 6.17.

The distance limit of 10 km was set in accordance with information from interviews and literature, as a reasonable maximum travel distance. After the first modelling, some deficits arose, as can be seen in Fig. 6.17. In a second modelling, infinite travel distance was assumed in order to see the maximum area required if all needs for fuel wood should be met. The result from this modelling is presented in Fig. 6.18, and some of the major deficits found are shown in Tab. VI.1.

 Tab. VI.1. Data on the fuelwood situation in the four major towns of the study area, after two steps of supply/demand modelling.

Town	Original demand (tons)	Deficit step 1 step 1 (tons)	Travel dist. step 2 (kms)
El Obeid	100 000	92 711	32
Bara	10 394	5 356	22
Er Rahad	16 341	9 470	15
Umm Ruwaba	26 095	17 201	21

Demand and deficits are in tons per year.

8. TRANSPORTATION MODELS

If the network of roads in a landscape is known, a simple model calculating the distance to the nearest road for pixels can be applied. Further development of this model may be to count both the distance along the roads from e.g. a main market and the distance from a road. Distances can be measured in length units as well as time or cost units. In Fig. 6.19 (page 148), an equidistance map of the road network in the study area is presented. Only roads with more or less regular lorry traffic considered.

9. CONCLUSION AND DISCUSSION

In this chapter, a number of theoretical models for representation of human activities and human features of the landscape have been described. They will be further discussed and applied in the subsequent chapters 8 and 9. I must however stress the importance of empirical studies in the field, in order to investigate the relationship between the models and reality.

The potential of spatial models, in combination with remote sensing and GIS, for resource monitoring is probably enormous. Together with the development of remote sensing techniques, towards more accurate quantification of e.g. biomass and crop yield, the spatial models will be increasingly useful, for the study of supply and demand of resources. Concepts like population density and carrying capacity will probably be revised when more adequate ways of describing population parameters are available.

It must however be stressed, that there are many weaknesses in the approach described in this chapter. Generally there is a risk of treating the human factors and the society as static factors that can be described by the conventional statistical methods. In the real world it is very difficult and risky to generalize the behaviour of human beings in this way. The

models described here shall however be seen as the first attempt only, to solve some of the technical problems, and make it feasible to integrate data of different types from different sources. In order to adapt the models further to the real world, we need much more empirical research on the interaction between man and nature, and this research has to be interdisciplinary.

seven

Analysis of Climatic Conditions

1. INTRODUCTION

Climatic conditions as a major factor causing and controlling desertification have been described and analysed by several authors. The role of climate in drought catastrophes has been discussed by scientists from many different disciplines, natural as well as human disciplines. General statements like "drought is a natural phenomenon but famine is an economic and political phenomenon" have been common in the press as well as in scientific literature. Cliffe (no date) wrote "The famine in Ethiopia as in the Sahel is not simply a natural disaster but has social and economic origins", and Meillasoux (no date) "if the drought can be seen as an act of nature, the same cannot be said for the famine". This may very well be true in many cases, but it is inevitable that the climatic conditions play the major role for food production, at least when subsistence agriculture in dry areas is considered. In this chapter the relationship between climate and different aspects of land degradation will be scrutinized.

Drought as a phenomenon has no generally accepted definition. WMO, in a special issue on Drought (WMO 1975) stated: "A most important factor in understanding drought, often not included in definitions, is that it is a "supply and demand" phenomenon". A satisfactory definition could be: "lack of sufficient water to meet the requirements" (ibid.).

Two previous reports (Olsson 1982 and 1983) examined different climatic parameters and the relationships between climate and desertification in the central Sudan. The conclusions that could be drawn from those studies are summarized, revised and developed in this chapter. For a more detailed treatment of climatic conditions the reader is referred to the reports by Olsson (1982 & 1983).

2. CLIMATIC DATA - AVAILABILITY AND ANALYSIS

2.1 Availability of Climatic Data in the Sudan

The network of meteorological observation stations is administered by the Sudan Meteorological Department. The network consists of three types of recording stations, meteorological

stations, rainfall stations and agrometeorological stations. The following variables are reported from the three categories of stations:

1. Meteorological stations:

air temperature
atmospheric pressure
wet bulb temperature
vapour pressure
relative humidity
rainfall (amount and intensity)
wind (force and direction)
ratio sunshine hours/potential sunshine hours
visibility

2. Rainfall stations:

rainfall on a daily basis

3. Agrometeorological stations:

the variables under 1.
in addition to this, they report on temperature conditions below and above the surface, wind at different levels above the surface and estimates of evaporation.

The number of stations in the network has varied over the years, Tab. VII.1 shows the number of stations in each category for the entire country and the N. and S. Kordofan Provinces.

Table VII.1. Number of weather stations in the Sudan and Kordofan Province.

	Meteorological		Rainfall		Agrometeorological	
	Sudan	Kordof.	Sudan	Kordof.	Sudan	Kordof.
1950	61	3	418	30	- -	- -
1960	72	3	561	45	- -	- -
1970	85	10	577	48	- -	- -
1975	95	12	424	37	- -	- -
1980	74	10	367	35	9	1
1983	51	6	97	10	8	1

Source: Sudan Meteorological Dept.

For studies of climatic impact on land degradation or land use it is necessary to work with data with a high spatial resolution. Due to the very sparse network of true meteorological stations, the only climatic parameters that can be used are

those provided by the rainfall stations. The spatial distribution of the stations used in this study are shown in Fig. 7.1. Unfortunately, many of the stations operational during the 1960s and 1970s have been omitted during the last years, resulting in a very sparse network of rainfall stations also in the study area.

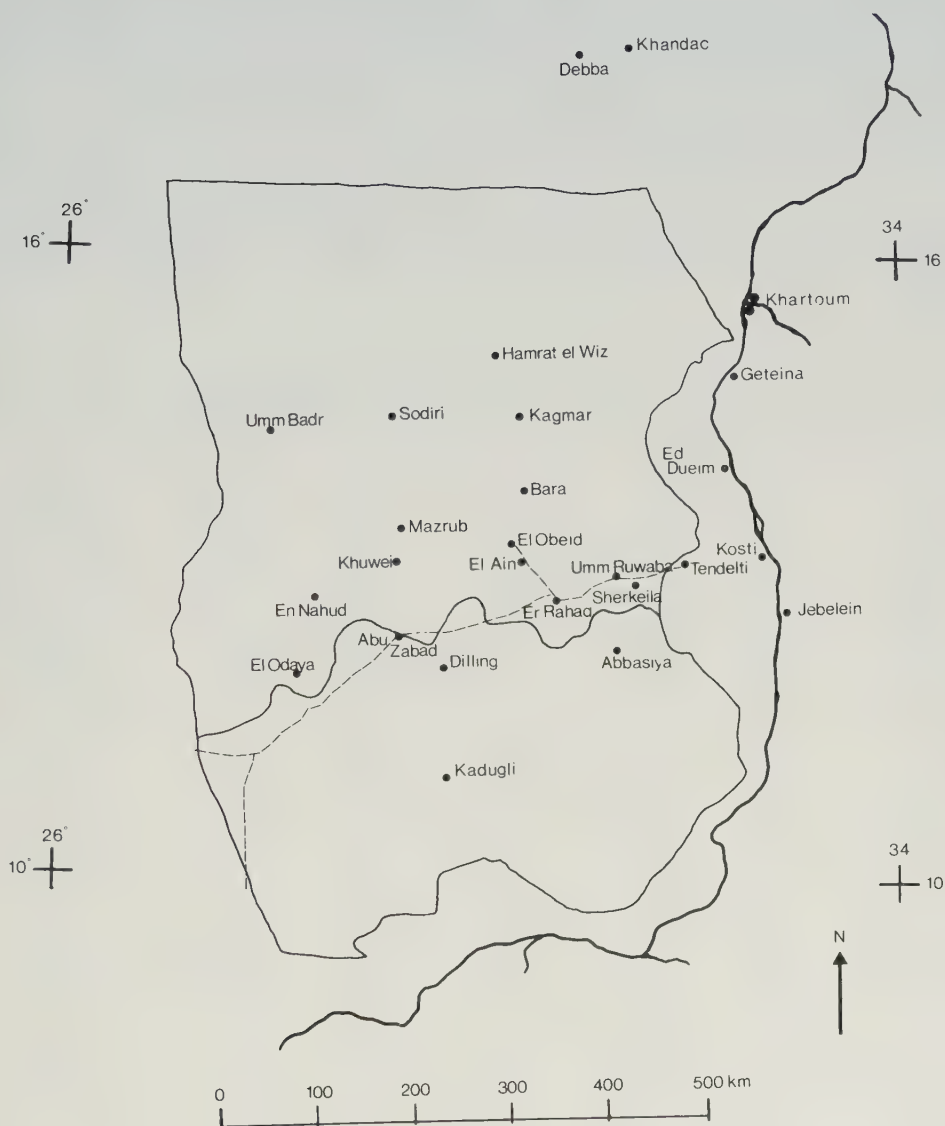


Fig. 7.1. Map showing the distribution of the rainfall stations analysed in this study.

2.2 Statistical Analysis of Climatic Data - Special Considerations.

The arid and semi-arid climates are characterized by extremely high rainfall variability, from one year to another as well as from one place to another. Special caution must therefore be taken when analysing climatic data by statistical methods. Most standard statistical methods assume the data to be normally distributed. It has been shown that semi-arid rainfall series are often positively skewed (Gregory 1969, Katz & Glantz 1977, Olsson 1983 and Trilsbach & Hulme 1984). This is also true for some of the rainfall stations in the central Sudan.

Skewness is a statistical measure that determines the degree of normality, or symmetry, of a distribution. The computing formula can be found in most statistical textbooks or e.g. Nie et.al. (1975). The value of skewness will be zero for a completely symmetric bell-shaped curve. A positive value indicates positive skewness while negative values indicates negative skewness.

Table VII.2. Total rainfall during June to September

STATION	No. Yrs	MEAN	STD	CV	IAV	SKEW.
En Nahud	33	350.9	113.1	32	33	-0.4
Dilling	32	493.0	142.7	29	27	0.1
Abu Zabad	26	394.2	132.4	34	32	0.7
Er Rahad	32	392.2	112.9	29	22	1.6
Abbasiya	30	473.1	96.4	20	26	0.0
Sherkeila	27	372.7	119.5	32	34	-0.1
Umm Ruwaba	31	358.2	91.9	26	25	0.3
Jebelein	31	339.8	110.3	32	26	-0.3
Khuwei	31	299.9	93.8	31	34	0.2
Mazrub	29	285.7	97.4	34	38	1.0
El Ain	22	327.7	206.5	63	46	2.0
El Obeid	33	317.7	119.3	38	37	0.2
Bara	31	241.6	72.7	30	35	0.3
Tendelti	29	306.0	88.1	29	30	-0.1
Kosti	33	353.7	106.9	30	29	-0.6
Fashashoya	30	301.1	85.5	28	36	0.4
Ed Dueim	32	254.5	89.3	35	40	0.9
Umm Badr	24	220.3	91.4	41	42	0.1
Sodiri	26	186.9	72.4	39	43	0.7
Geteina	31	181.5	88.2	49	49	0.9
Hamrat El Wuz	19	170.9	70.5	41	46	0.5
Khartoum	29	139.5	58.3	42	44	0.8
Debba	24	40.0	41.5	104	115	1.2
Khandaq	22	25.9	28.8	111	134	1.4
Korti	18	40.9	34.9	85	87	0.9

CV = coefficient of variation, IAV = interannual variability,
SKEW = skewness index

A positive skewed distribution may be transformed to a more normally distributed one or even to a negative distribution by logarithm or square root transformation. Tab. VII.2 shows the skewness values for a number of stations in central Sudan. Few stations, however, showed severely skewed distributions.

The degree of variability can be measured by the standard deviation. For comparative purposes, the coefficient of variation is more suitable since this measure is independent of the magnitude of the mean value. Another index of variability that can be used for comparison between stations with varying magnitudes of mean is the inter-annual variability described by Wallen (1967). This index measures the percentage ratio of the mean inter-annual-rainfall-difference to the mean annual rainfall.

3. TIME SERIES ANALYSIS

Although the time series analysed include the Sahelian drought

Tab. VII.3. Number of days with at least 1 mm rainfall, June -
September

STATION	No.Yrs	MEAN	STD	CV	IAV	SKEW.
En Nahud	32	30.4	8.5	28	25	-1.2
Dilling	31	33.0	7.6	23	22	-0.4
Abu Zabad	26	29.0	5.7	19	20	-0.9
Er Rahad	31	28.6	7.2	25	21	0.2
Abbasiya	30	37.1	7.5	20	20	-0.8
Sherkeila	27	25.2	6.1	24	26	-0.2
Umm Ruwaba	31	24.0	4.6	19	17	0.9
Jebelein	30	21.3	5.0	24	24	-0.1
Khuwei	31	20.2	5.0	25	26	-0.4
Mazrub	29	19.4	4.1	21	22	0.6
El Ain	22	19.7	5.0	25	21	-0.1
El Obeid	31	29.1	6.4	22	18	0.3
Bara	31	18.3	4.1	23	26	0.2
Tendelti	29	18.5	7.4	40	35	3.2
Kosti	31	32.0	5.8	18	15	0.6
Fashashoya	30	21.1	6.0	28	24	0.2
Ed Dueim	31	19.9	5.9	29	35	0.6
Umm Badr	24	17.4	4.1	23	23	0.3
Sodiri	26	14.7	5.2	35	33	0.4
Geteina	30	12.8	4.9	38	37	0.5
Hamrat El Wuz	19	14.5	5.5	38	38	1.0
Khartoum	28	13.3	4.0	30	31	0.5
Debba	24	4.2	3.4	79	95	0.5
Khandaq	21	3.1	2.1	67	100	0.1
Korti	18	4.2	2.5	60	66	0.0

CV = coefficient of variation, IAV = interannual variability,
SKEW = skewness index

1968-1974 and to some extent also the present extremely dry situation, there are no clear evidences of a secular negative trend in the amount of rainfall. Three long time series (over 70 years), El Obeid, Bara and En Nahud, and 13 short time series (30 - 33 years) were analysed. Figs. 7.2 and 7.3 show some of the time series plotted. The trendline, percentage trend and coefficients of explanation for the trends are indicated.

The number of days with at least 1 mm of rainfall showed however a clear negative trend for the four stations analysed in Olsson (1983). At the time of publication of that report, the rainfall records for some of the years were lacking. They have now been included in the analysis and the result is shown in Fig. 7.4. and Tab. VII.3.

The presence of a strong trend in number of days with rainfall, in contrast to the amount of rainfall, corresponds well with the low correlation found by Trilsbach & Hulme (1984) between number of days with 1 to 10 mm rainfall and total annual rainfall.

The percentage trend and coefficient of explanation for the trends in both total amount of rainfall and number of days with rainfall (June - September) are shown in Tab. VII.4. Only the stations with at least 29 years of observations are included.

 Tab. VII.4. The percentage trend (first column) and the coefficient of explanation of the trend (second column) in amount of rainfall and number of days with at least 1 mm rainfall. Data for July - September.

STATION	No. Yrs.	AMOUNT		No DAYS	
En Nahud	33	-28	4.8	-18	17.2 *
Dilling	32	-12	0.1	-3	2.5
Er Rahad	32	-29	12.9 *	-30	58.8 **
Abbasiya	30	-18	2.2	-10	12.0 *
Umm Ruwaba	31	-26	23.1 **	-36	18.9 **
Jebelein	31	-36	39.2 **	-51	28.8 **
Khuwei	31	1	6.8	-27	1.1
Mazrub	29	-3	0.2	-6	0.2
El Obeid	33	-41	16.9 *	-36	39.8 **
Bara	31	-22	3.4	-19	8.2
Tendelti	29	1	4.9	-22	17.9 *
Kosti	33	-28	2.2	-12	32.1 **
Fashashoya	30	-35	2.2	-14	14.5 *
Ed Dueim	32	-37	6.8	-27	18.8 **
Geteina	31	-28	12.6 *	-48	6.8
Khartoum	29	-41	17.1 *	-43	22.2 **

 ** = 99 % significant trend

* = 95 % significant trend

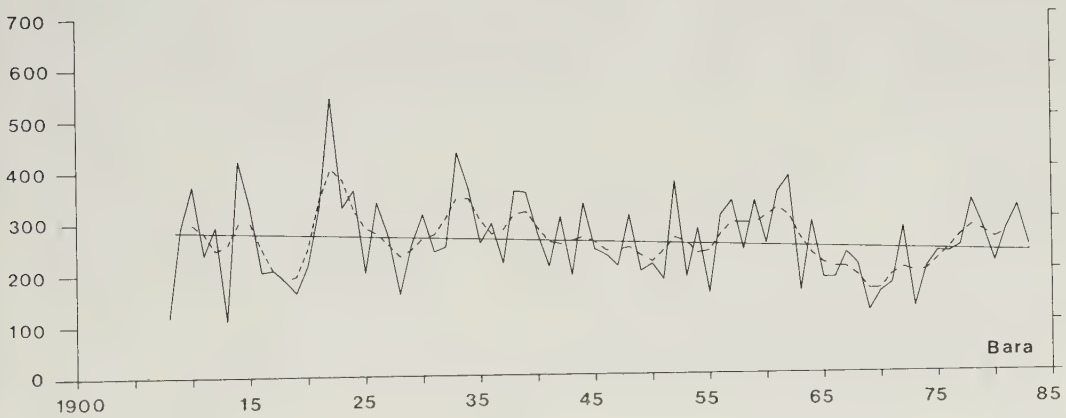
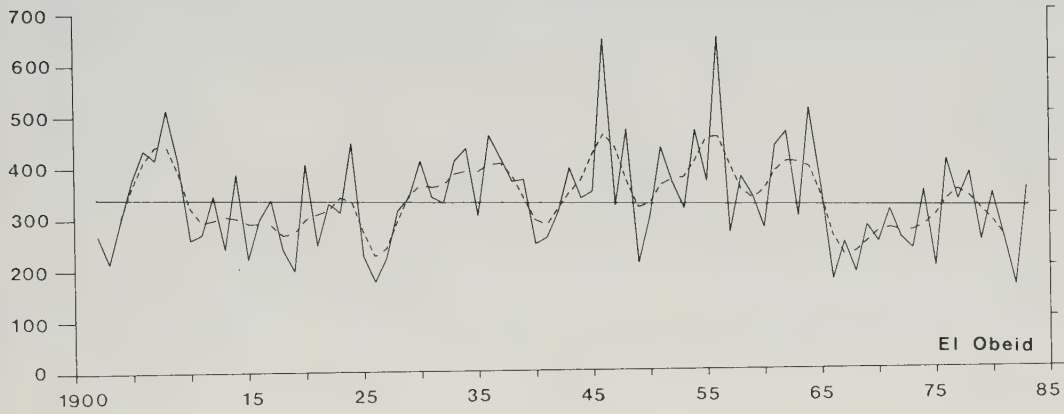
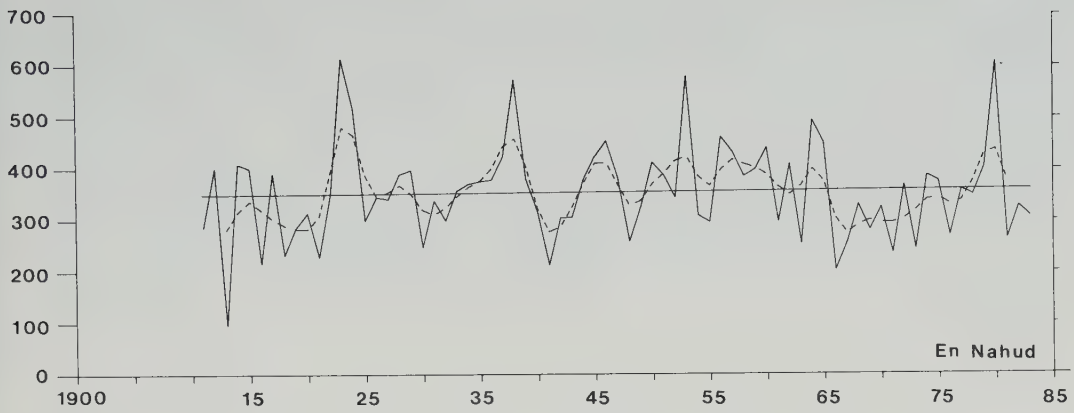


Fig. 7.2. The time series for El Obeid, Bara and En Nahud plotted with a 5 year smoothing filter (dashed line). The trend line is indicated.

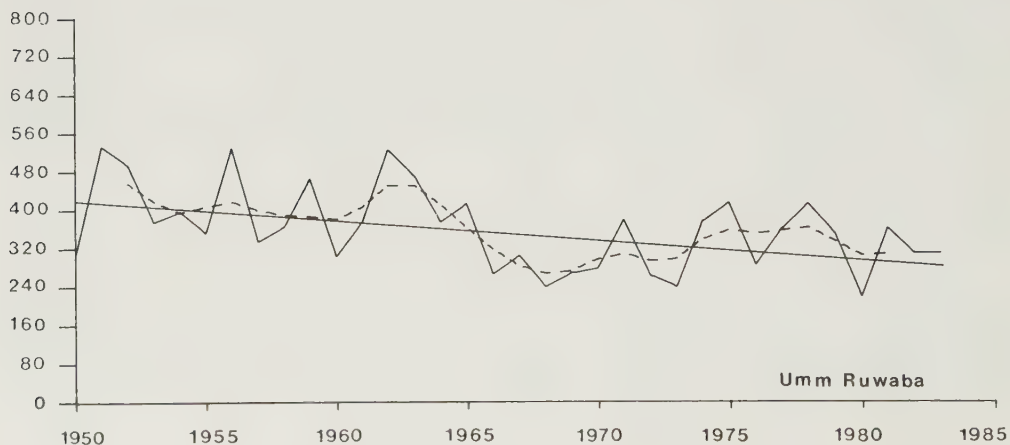
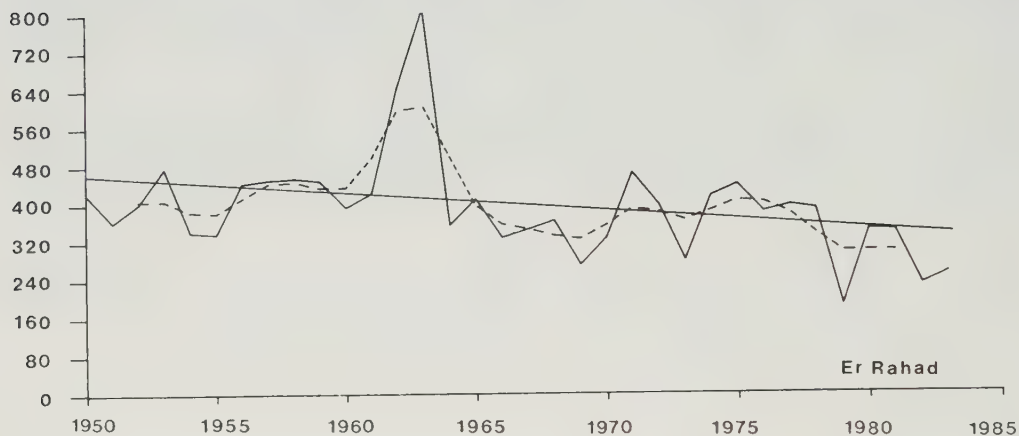
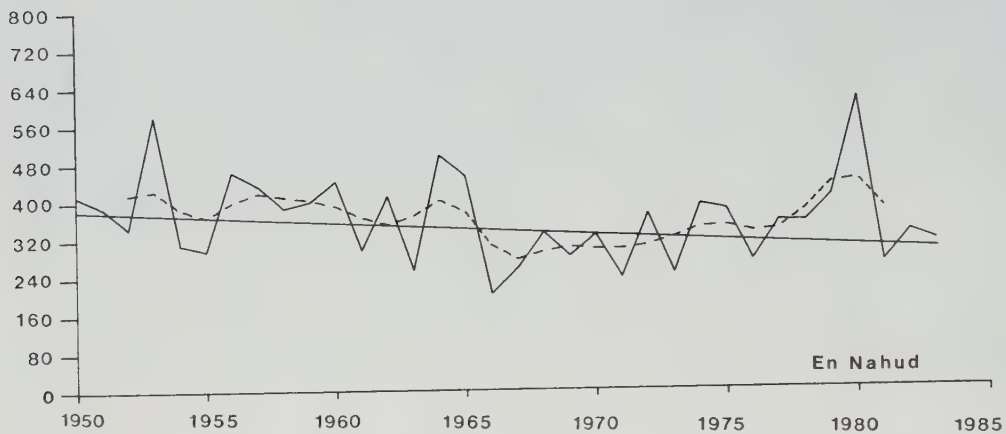


Fig. 7.3. The short time series, showing total rainfall June - September, for En Nahud, Er Rahad, Umm Ruwaba, Jebelain, El Obeid and Kosti plotted with a 5 year smoothing filter (dashed line). The trend line is indicated, see Tab. IIV.4.

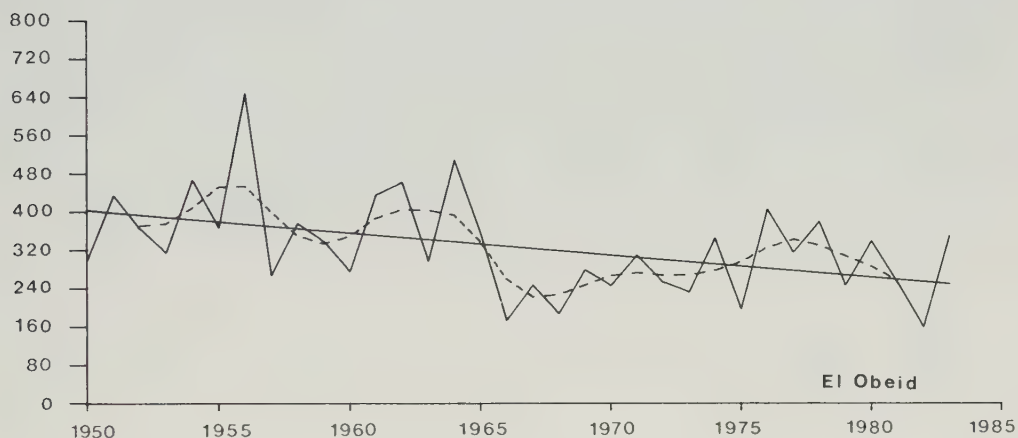
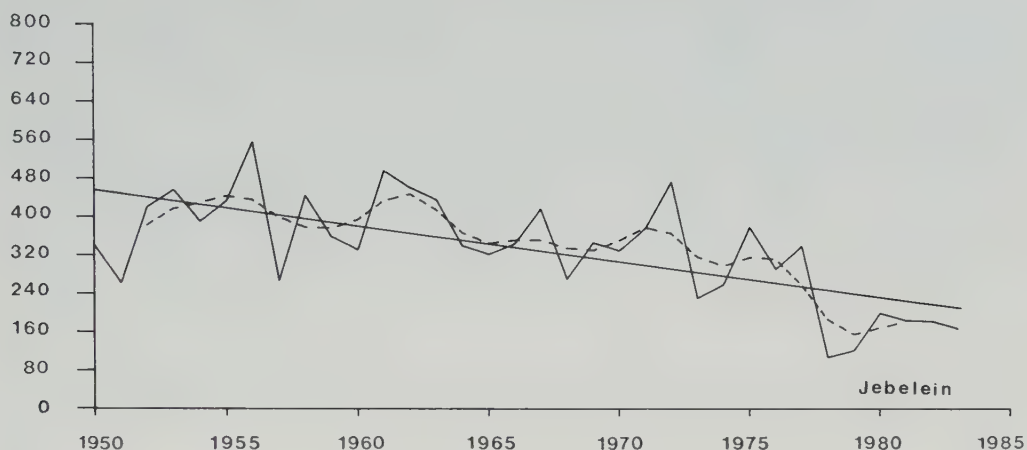


Fig. 7.3. The short time series, showing total rainfall June - September, for En Nahud, Er Rahad, Umm Ruwaba, Jebelein, El Obeid and Kosti plotted with a 5 year smoothing filter (dashed line). The trend line is indicated, see Tab. IIV.4.

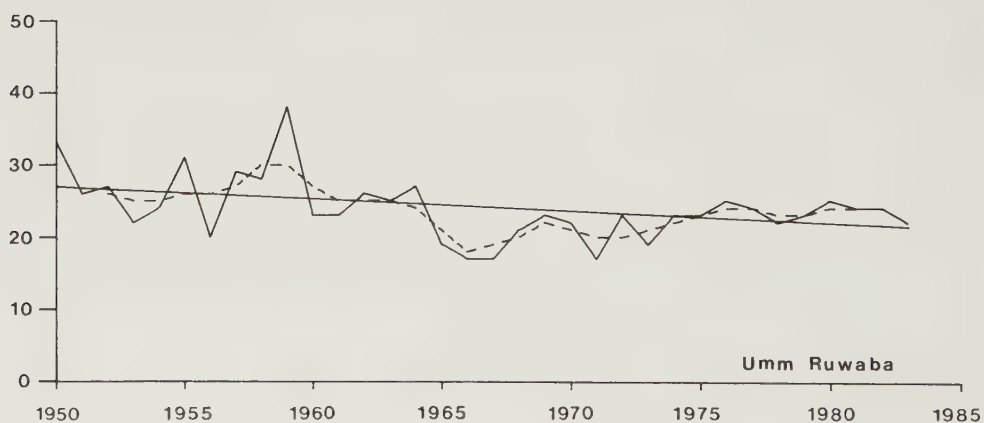
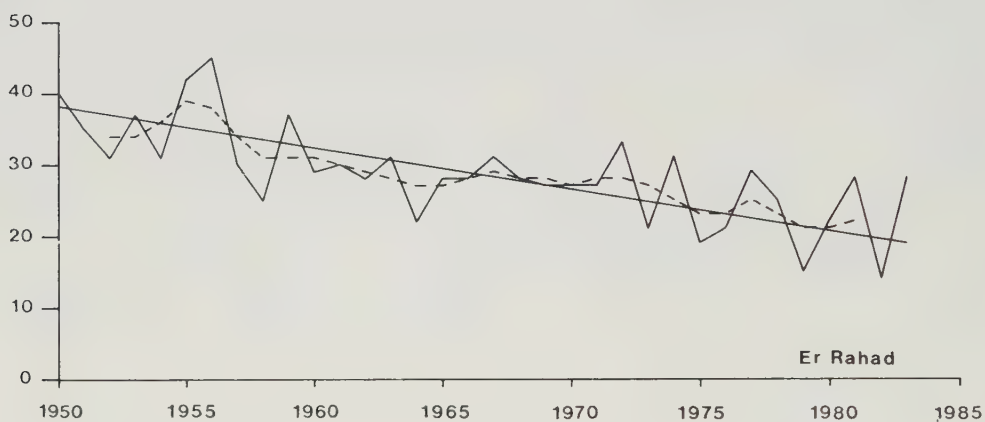
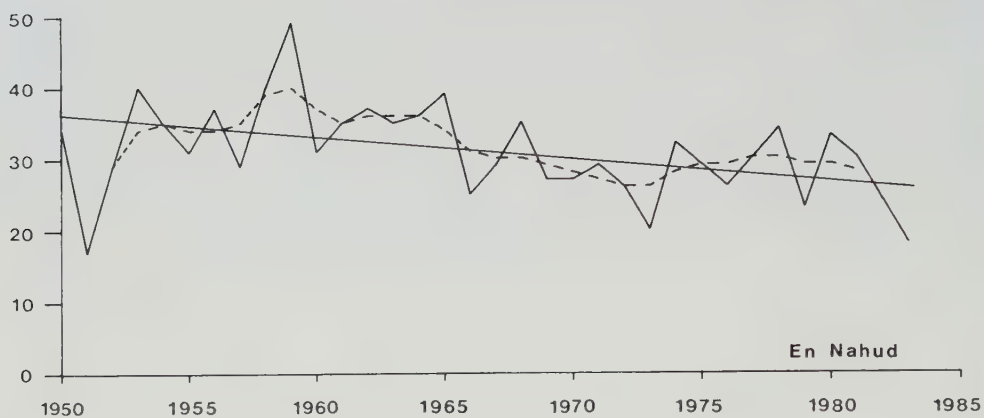


Fig. 7.4. The number of days with at least one mm of rainfall for En Nahud, Er Rahad, Umm Ruwaba, Jebelein, El Obeid and Kosti, plotted with a 5 year smoothing filter (dashed line). The trend line is indicated, see Tab. IIV.4.

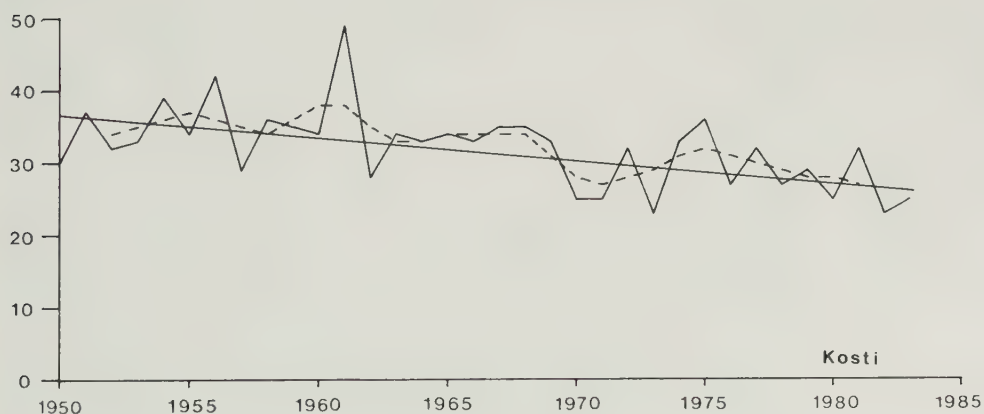
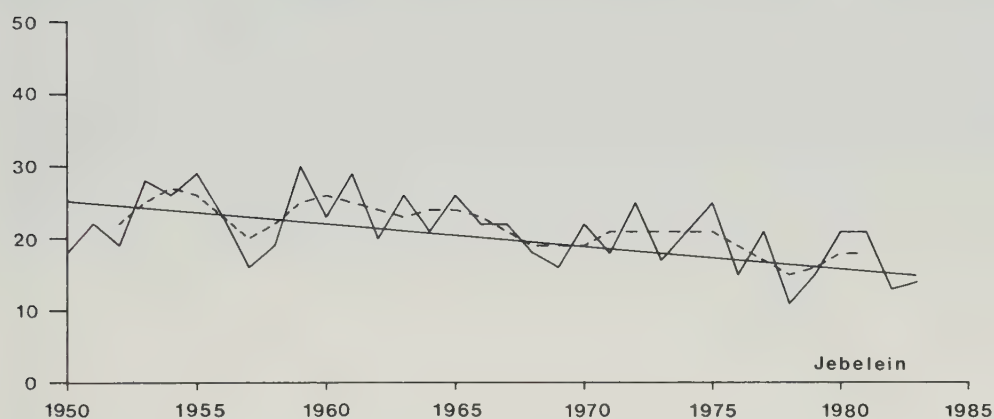
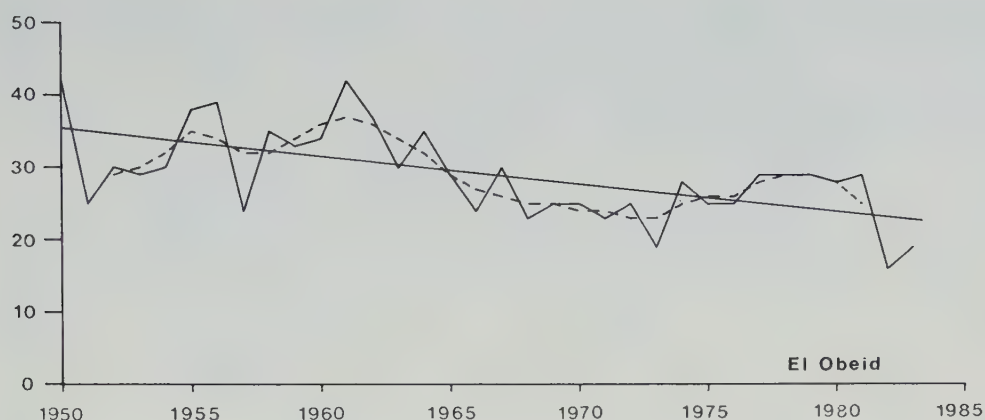


Fig. 7.4. The number of days with at least one mm of rainfall for En Nahud, Er Rahad, Umm Ruwaba, Jebelain, El Obeid and Kosti, plotted with a 5 year smoothing filter (dashed line). The trend line is indicated, see Tab. IIV.4.

The variation from one year to another is substantial and increases with increasing aridity. Descriptive statistics for some of the analysed stations were shown in Tabs. VII.2 and VII.3. The inter-annual variability (IAV) is sensitive to the rapid changes of rainfall from one year to another while the coefficient of variation measures the total magnitude of variation.

In order to investigate the presence or not of periodic variations in the time series spectral analysis was carried out in Olsson (1983). Spectral analysis involves the fitting of a fourier series (i.e. a sinusoidal function) to a time series. The analysis gives a result where it is possible to determine the degree of explanation of the total variance by cyclic variations for different harmonics. The mathematical theory behind spectral analysis is described in most standard mathematical text books. The application on time series in climatology is described in e.g. Panofsky & Brier (1958) and Sumner (1978).

Due to the rather short time series of most of the stations, only the shorter periods can be treated as being of significance. The three long time series showed a weak tendency of periodicity at 8 - 13 years. These periods explained approximately 10 percent of the total variation. The time series are however too short to allow any reliable conclusions. The often found quasi-biennial variation, which causes two to three years persistence of dry or wet spells, was not found to be very strong, not more than 4 - 6 percent.

4. SPATIAL DISTRIBUTION OF RAINFALL

The variation in space of rainfall was demonstrated by Trilsbach & Hulme (1984). They demonstrated that the spatial localization of rainfall does not "average out" over short periods. Not even on a 5-year period had the spatial pattern been smoothed. It is important to bear this in mind when working with spatial distribution of the data in a geographical information system. Interpolation of rainfall data from short time series into a regular grid net can be very misleading.

All moisture in the study area is transported by south-westerly winds from the Atlantic Ocean. The topography of the Nuba Mountains will probably have some influence on the rainfall pattern in the study area, a broad overview of the topography is presented in Fig. 7.5.

The spatial pattern of average rainfall is shown in Fig. 7.6. It can be characterised as a gradual downstep in rainfall when going northwards. There are no prominent anomalies in the pattern, caused by any external influence on the climate.

The pattern of number of days with at least 1 mm of rainfall shows however a much more complex spatial pattern, see Fig 7.7. There are two distinct anomalies, which have no correspondence in the average rainfall map. The pattern is probably affected by the Nuba Mountains. It is, however, interesting to see the

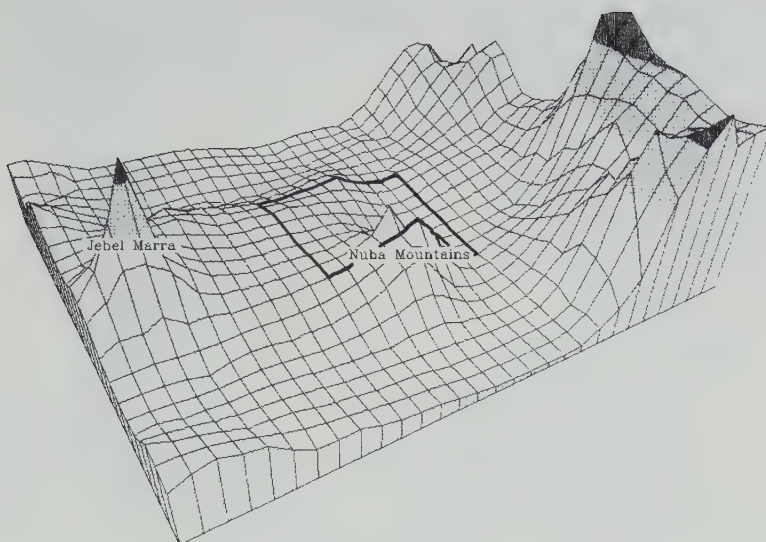


Fig. 7.5. A broad overview of the topographic features of the Sudan. The frame indicates the area between Lats. 12 - 16 and Longs. 28 - 33.

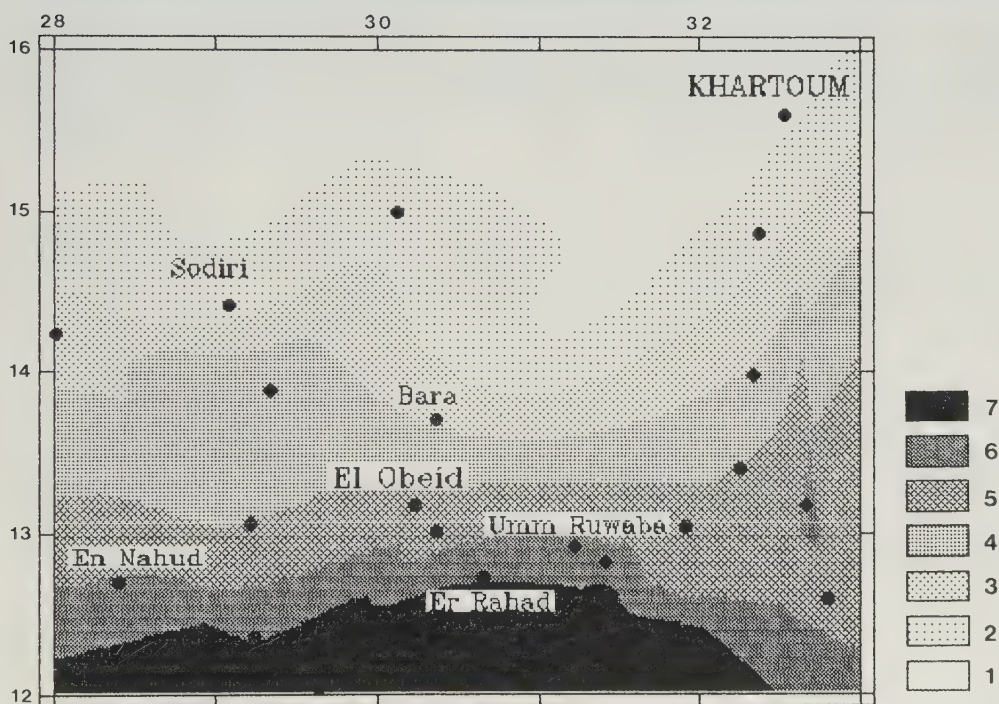


Fig. 7.6. Map showing the the spatial distribution of amount of rainfall, based on interpolation from the stations showed in Fig. 7.1. 1 = 0 - 150 mm, 2 = 150 - 200 mm, 3 = 200 - 250 mm, 4 = 250 - 300 mm, 5 = 300 - 350 mm, 6 = 350 - 400 mm and 7 = above 400 mm.

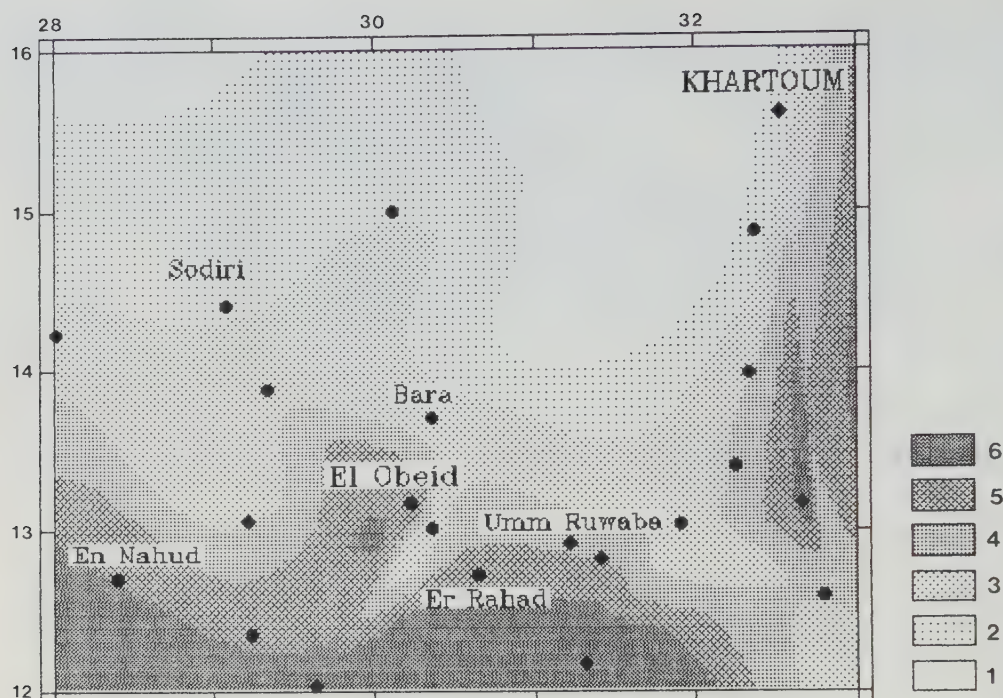


Fig. 7.7. Map showing the the spatial distribution of number of days with at least one mm of rainfall, based on interpolation from the stations showed in Fig. 7.1. 1 = 0 - 10 days, 2 = 10 - 15 days, 3 = 15 - 20 days, 4 = 20 - 25 days, 5 = 25 - 30 days and 6 = more than 30 days.

difference in topographical dependence, between the amount of rainfall and the number of days with rainfall.

Trilsbach & Hulme (1984) studied the relationship between annual rainfall and number of days with rainfall for several stations in central Sudan. They found generally low correlation between number of days with up to 10 mm rainfall and annual rainfall. The drier stations, between 14 and 16 degrees, showed a marked higher correlation (average 0.32) than the stations with higher annual rainfall, between latitude 12 and 13, (average 0.15). This indicates that the light rainfall is independent of the annual amount of rainfall, especially in the southern, wetter parts of the area.

In order to include both magnitude and variability in one measure, the rainfall reliability, according to a method described by Glover and Robinson (1953), is suitable. It is based on normal probability distributions of rainfall. Maps showing the probability of receiving a certain amount of rainfall were generated as well as maps showing the probability of having a certain number of days with at least 1 mm of rainfall, see Figs. 7.8 & 7.9. The advantage of this way of

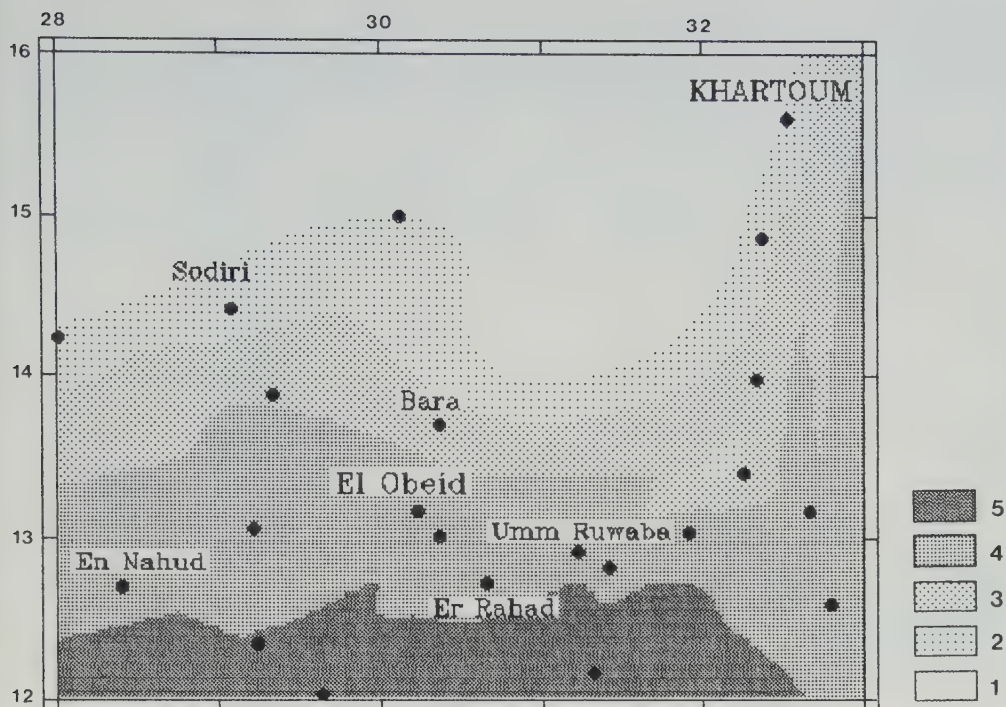


Fig. 7.8. Map showing the probability of receiving at least 60 mm rainfall per month for three consecutive months (July - September), based on interpolation from the stations showed in Fig. 7.1. 1 = 0 - 10 %, 2 = 10 - 20 %, 3 = 20 - 30 %, 4 = 30 - 40 % and 5 = over 40 %.

representing rainfall is that two properties, average and variability, can be presented in one measure. The probability of receiving a certain amount of rainfall should be a good alternative to mean annual rainfall, when describing climatic conditions of a region.

5. AGRONOMIC DRY BOUNDARY

Theoretical cultivation limits, so-called agronomic dry boundaries, are often expressed by climatical parameters, e.g. mean annual rainfall. Ibrahim (1978 and 1980) defined the agronomic dry boundary in western Sudan as 8 arid months per year. This boundary follows in the Sudan approximately the 600 mm isohyet for mean annual rainfall. Ibrahim (1980) also mentions that empirically the agronomic dry boundary in Darfur lies somewhere between 500 and 600 mm yearly rainfall. The map in Fig. 2.1 shows the position of these isolines in the study area. One weakness of this way of delineating areas of appropriate land use is that the variability of rainfall has not been considered. A more relevant measure to be used for definition of agronomic dry boundary should be the probability of receiving a certain amount of rainfall, e.g. for millet 300 mm.

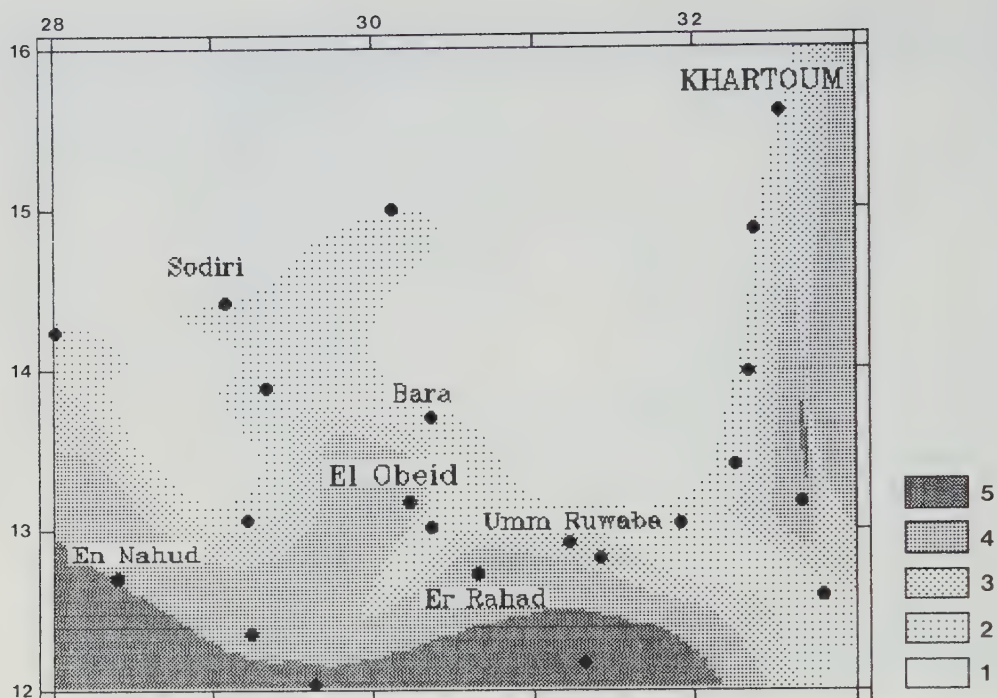


Fig. 7.9. Map showing the probability of having at least six days with at least one mm rainfall per month, for three consecutive months (July - September), based on interpolation from the stations in Fig. 7.1. 1 = 0 - 10 %, 2 = 10 - 20 %, 3 = 20 - 30 %, 4 = 30 - 40 % and 5 = over 40 %.

The lack of validity of this way of determining agronomic dry boundary is clearly illustrated by the fact that almost the entire Qoz region of Kordofan lies to the north of this limit. This should mean that areas that have been under cultivation for centuries should not be appropriate for cultivation.

In areas with highly variable rainfall and different soil regions as well, it is necessary to find more relevant approaches for determining theoretical cultivation limits.

An empirical way of defining the limit for appropriate land use was suggested by Olsson (1982). Through interpretation of Landsat imagery from 1972/73 and 1979 areas, considered as being over-used were mapped. The season 1972/73 belonged to one of the driest ones during the Sahelian drought. Vast areas were considered to be over-used by cultivation and grazing. In 1978/79, the rainfall was approximately normal and had been so for a number of years. The areas most severely over-used in 1972/73 showed clear signs of recovery (the areas north and north-east of Umm Ruwaba) in 1979. Therefore, I maintain that this area has a fairly appropriate land use. Signs of overexploitation were only evident during extremely dry periods. North of this zone, between Umm Sayila - Gabra Es Sheikh - Kagmar, the

opposite conditions were found. In 1972/73, a cultivation pattern was clearly seen, i.e. there was enough natural vegetation around the fields to make up the typical patchy pattern of cultivated areas. In 1979, the cultivation pattern had been erased, which is an indicator of decreasing vegetation cover. This area has inappropriate land use which is evident by the increase of over-used areas even during a wet or normal period. See further discussion in Chapter 8 and 9.

6. CROP WATER REQUIREMENT

The requirement of water of the most important crop in the study area, millet (*Pennisetum typhoides*, Arabic: dukhn) was discussed by Olsson (1982). A minimum level of rain needed by millet without substantially affecting grain yield was set by Dancette (1976) to 80 % of the water requirement of well watered crop (ETm). ETm for millet is about 320 mm during the growth season (90 days). Accordingly, the moisture requirement of millet was set to 80 mm per month for three consecutive months (July, August and September). This amount of rainfall does not correspond to maximal water needs of millet but permits the crop to survive and produce an adequate harvest (Dancette & Hall 1979).

The probabilities of receiving this amount of rainfall are given in Tab. VII.5. for a number of stations in the study area.

7. RAINFALL, CROP YIELD AND DESERTIFICATION

Crop yield is often considered to be one of the most important indicators of desertification (see e.g. Reining 1978). According to the Sudan Government (DECARP 1976), "Food production has declined and continues to decline because of soil deterioration associated with desert encroachment". This quotation was illustrated by the diagram in Fig. 2.8.

If one correlates these productivity figures with the annual rainfall at a relevant station, e.g. En Nahud or El Obeid, one finds that the correlation is rather low. Only 5 - 10 % of the total variation in the crop yield can be explained by the annual rainfall. The number of days with rainfall is however significantly higher correlated with the yield. The correlation between productivity and number of days with at least 1 mm of rainfall at En Nahud is 0.81, i.e. 66 % of the total variation can be explained. A multiple regression analysis between rainfall and yield at four stations resulted in a multiple regression coefficient of 0.92, i.e. 85 % of the variation could be explained (Olsson 1983). The correlation was however based on data where the driest years during the sahelian drought (1968 - 1974) were lacking. With these years included, the correlation becomes somewhat lower. The correlation between the mean number of days with at least 1 mm of rainfall (during June - September) for El Obeid, En Nahud, Umm Ruwaba, Er Rahad

Tab. VII.5 The probability of receiving at least 80 mm rainfall per month for the three wettest months, July, August and September, and distributed over at least 6 days per month.

	JULY		AUGUST		SEPTEMBER	
	P(80)	P(6)	P(80)	P(6)	P(80)	P(6)
En Nahud	81.4	90.1	76.0	86.8	34.6	61.9
Dilling	86.5	86.8	91.3	87.6	75.7	72.3
Abu Zabad	73.3	79.0	74.8	91.4	56.5	65.1
Er Rahad	82.4	84.7	76.0	86.7	35.2	44.4
Abbasiya	87.5	91.7	89.4	95.4	69.8	98.9
Umm Ruwaba	78.5	74.9	78.7	80.3	31.2	27.4
Jebelein	62.7	47.0	79.7	77.6	34.2	21.0
Khuwei	56.9	45.9	72.6	58.7	34.8	24.9
Mazrub	57.1	50.5	76.0	68.9	22.4	10.2
El Obeid	68.0	82.0	82.5	92.6	29.1	50.0
Bara	60.1	52.5	62.3	58.6	9.9	8.5
Tendelti	53.1	33.8	78.1	58.4	40.1	11.9
Kosti	72.0	89.1	79.1	98.5	38.9	48.0
Ed Dueim	48.2	47.3	70.0	66.0	11.3	14.7
Umm Badr	51.7	51.9	60.3	49.3	0.1	7.7
Sodiri	44.4	46.0	48.4	45.6	2.6	2.0
Geteina	37.9	32.0	44.1	37.0	8.6	0.6
Hamrat El Wiz	45.1	43.0	40.0	31.4	0.0	2.8
Khartoum	24.9	27.4	37.9	36.6	1.5	4.1

and Bara, and millet yield was 0.83 (0.05). The multiple correlation coefficient between mean number of days and the mean amount of rainfall, and millet yield was slightly higher, 0.84 (0.05), i.e. 71 % of the total variation in crop yield could be explained by the rainfall parameters. The regression equation is presented in Chapter 8.

The drastic decline in productivity in spite of the lack of a significant negative trend in the amount of rainfall can most likely be explained by the very strong trend in decreasing number of days with rainfall, see Fig. 7.10.

It can be discussed if number of days with more than 1 mm of rainfall is the most appropriate rainfall parameter to use in this respect. The sources of meteorological data give however only two choices, number of days with more than 1 mm of rainfall or number of days with more than 10 mm of rainfall. The light soils in the study area together with the dominance of millet makes very light rainfalls useful. Trilsbach & Hulme (1984) found significant correlation for most stations between number of days with more than 10 mm of rainfall and amount of rainfall, in contrast to the correlation between number of days with 1 to 10 mm rainfall and the amount. This also implies that

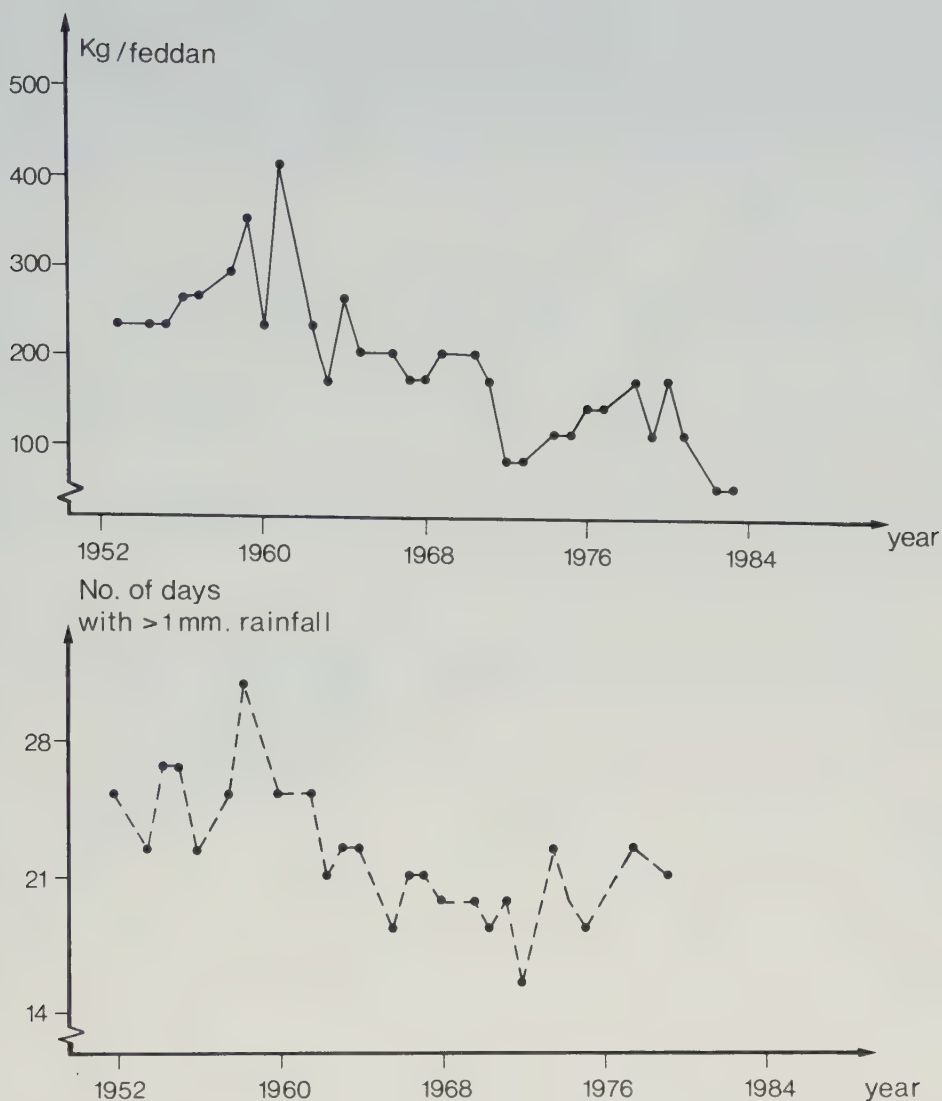


Fig. 7.10. The millet yield (upper curve) and mean number of days with at least 1 mm rainfall (lower curve) for the stations analysed.

the use of the 1 mm measure is appropriate, since we measure two different properties of the rainfall.

The very high correlation between rainfall and crop yield must be critically reviewed. A number of critical points can be raised.

1. Spatial autocorrelation.

When dealing with variables spatially distributed, one must be

aware of the risk of spatial autocorrelation, which may violate the interpretation of any regression model. The nature of rainfall, however, reduces this risk. The rainfalls are mostly rather local phenomena where the showers neither persist for a long time nor travel long distances. The correlation between stations is generally low. For a more detailed discussion of this see Trilsbach & Hulme (1984).

2. Erroneous data

The data set used may contain severe errors. Especially the data on agricultural productivity contain errors of unknown magnitude. The data are collected and presented by the Statistics Division, Department of Agricultural Economics. The millet cultivation is practised within the so-called traditional sector. The area covered by this sector is not known precisely as no cadastral measurements have been done. Area under cultivation, production and productivity are estimated by agricultural inspectors. "In reporting crop acreage and yield they use personal observations and judgement added by impressions of the local chiefs" (Statistics Division 1984).

The method is certainly rough and relatively large errors can be present in the data. However, there exists a strong causal relationship between crop yield and rainfall. It is therefore unlikely that data containing severe errors would result in the high correlation found.

The resolution of the data is very rough. Local variations of crop yield due to other factors than rainfall are impossible to detect. Furthermore, the areas most severely affected by land degradation are probably the most marginal ones, where the productivity is very low. These areas do not contribute sufficiently to the total production to influence the official statistics very much, which is integrated over vast areas. These areas are probably not as properly surveyed as the more productive and less remote areas.

3. There is no desertification or land degradation in the area, or these processes do not affect crop yield.

The study area has been, and still is, considered to be a region with very severe desertification, e.g. Lamprey (1975), DECARP (1976), Hammer-Digernes (1977), Hellden (1977) and UNSO (1981).

Desertification or land degradation is generally considered to reduce agricultural production through soil erosion and soil exhaustion. Wind erosion removes the fertile top soil or degrades the top soil by removal of the finest particles. Overgrazing and over-cultivation is considered to deplete the nutrients stored in the soil.

The millet produced in the study area is grown in Qoz soil, i.e. a soil consisting of almost pure sand. The sand is very

deep, tens of metres in most areas, and is weakly structured. Soil profiles have been investigated (Olsson, unpublished data) and the soil is usually very homogeneous in the whole profile. There is no clear distinction between top soil and subsoil. This may imply that removal of soil by erosion is not a severe problem as long as the sand sheet is deep enough.

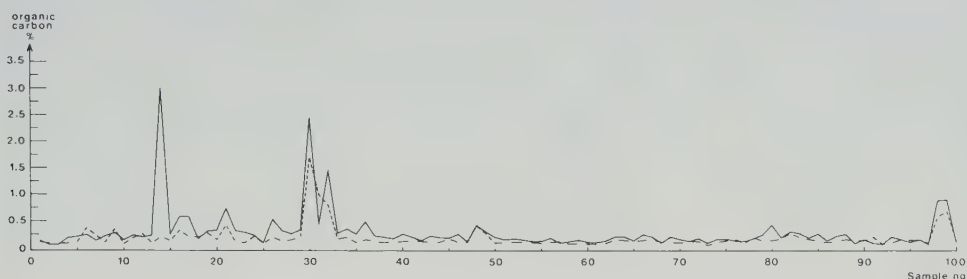


Fig. 7.11. Diagram showing organic carbon content in soil samples collected along a profile through the study area. Solid line shows samples from the surface and dashed line from 30 cm below the surface.

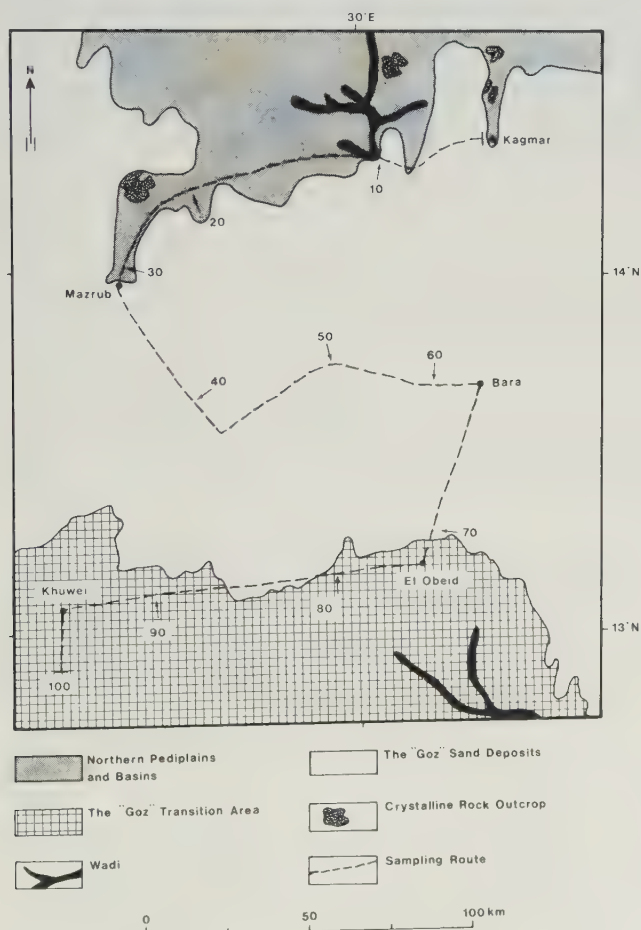


Fig. 7.12. Map showing the geographical position of the soil samples presented in Fig. 7.11.

The nutrient status of the soil is extremely low. Fig. 7.11 shows the content of organic carbon along a profile through the whole Qoz region, see Fig. 7.12 for position of the soil samples. The peaks at samples 12 - 15 and 29 - 34 correspond with wadis with very dense bush vegetation, as well as the last peak between 96 and 99. The most intensively cultivated area corresponds with samples 50 to 95. In this area the organic carbon content is extremely low. The most interesting feature is however the relationship between the two levels, the surface and 30 cm below the surface. Usually the highest concentrations of nutrients is expected to be at the surface, with a rapid decline downwards (Jones 1973). In the most intensively cultivated region the two levels have almost the same content or even the opposite situation, see Fig. 7.13. This indicates a soil surface subject to erosion or exhaustion. Once this stage has been reached, further land degradation may not affect the amount of nutrients available for the crop, provided that the soil profile is homogeneous.

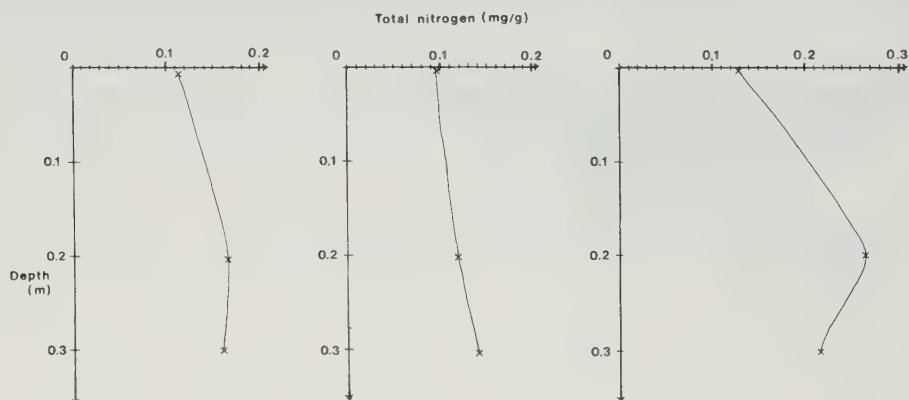


Fig. 7.13. Total nitrogen content of some soil samples from the cultivated Qoz region, from Olsson & Stern (1981).

The diagram in Fig. 7.11, also shows the difference between an area with natural vegetation and very little impact from agriculture (samples 10 to 40) and the intensively cultivated zone (40 to 95). The two levels in the first zone are clearly separated, the highest concentrations at the surface.

The diagrams in Figs. 7.11 and 7.13, indicate that land degradation processes (grazing and cultivation) are likely to affect the soil conditions. But it also indicates that continuing soil erosion and exhaustion in the cultivated area have a very little effect, since the nutrient status has been almost totally depleted. This is an indication that the biological productivity may be higher in areas with natural vegetation than in areas intensively cultivated. Further investigations

are necessary in order to determine the positive effects of fallow periods.

In arid and semi-arid areas the rainfall is often the major limiting factor for crop production. The more rainfall the more important becomes other factors, as e.g. nutrient status of the soil. Noy-Meir & Harpaz (1977) showed that crop yield in semi-arid Israel was limited by rainfall in areas receiving less than approximately 220 mm per year, and by nitrogen in more humid areas. According to investigations in Mali, the transition from growth determined mainly by nutrients to that determined by water occurs at lower annual rainfall, between 100 and 200 mm (Bremen & de Wit 1983). In areas with very sandy soil it is, however, likely to assume that this transition takes place at higher rainfall values due to the low water holding capacity.

8. CONCLUSION AND DISCUSSION

Although the availability of climatic data in the Sudan has significantly decreased during the last 10 years, a number of conclusions can be drawn. Several commonly assumed features of arid climates have been verified by the analyses. Two rainfall parameters, amount of rainfall and number of days with at least 1 mm of rainfall, have been investigated for 25 stations in N. Kordofan and adjacent areas. Only stations with at least 18 years of registrations have been included in the analyses.

8.1 Amount of Rainfall

A majority of all 25 stations analysed showed a slight positive skewness, the mean skewness value was 0.5. The variability of the stations increased with decreasing rainfall. Coefficient of variation and interannual variability ranged from 20 and 25, respectively to 111 and 134.

It was only possible to find a statistically significant trend in the data for 6 stations (only two were 99 % significant). All trends were negative and ranged from -26 % to -41 % for the significant stations.

The spatial pattern of amount of rainfall showed a fairly even decrease in rainfall northwards. Topographically induced rainfall anomalies were not very distinct.

The correlation between millet yield and amount of rainfall was generally low.

8.2 Number of Days with Rainfall

The tendency of positive skewness was not consistent. The southern stations generally showed a slight tendency of negative skewness, while the northern stations showed a positive skewness, the overall mean of skewnesses was 0.2. The variability of the distributions was generally much less than for the amount of rainfall, and the variability did not increase

significantly with decreasing rainfall, with the exception of the three driest stations.

A majority of the stations, 11 out of 16 stations with series longer than 29 years, showed a significant negative trend. Of those were 7 stations 99 % significant. The significant trends ranged from - 10 % to - 51 %.

The variation in space of number of days with rainfall showed a much more complex pattern than that of amount of rainfall. A marked topographic effect from the Nuba Mountains could be seen as a strong negative anomaly NE of the mountainous area, in contrast to the case of amount of rainfall.

The correlation between millet yield and number of days with at least 1 mm rainfall was generally very high. For e.g. En Nahud the correlation coefficient was 0.81, i.e. 66 % of the variation in crop yield could be explained by the number of rainy days.

Judging from these facts, one could say that the decrease in crop yield experienced since the early 1960s is due to pure natural factors beyond the control of man. Another question should, however, now be raised: what is the cause of the negative trend in number of days with rainfall reported at a majority of the stations analysed? Is the trend, though in most cases 95 % significant, just part of the natural variation and therefore random, or is it part of a climatic change?

eight

Population and Land Use

1. INTRODUCTION

The factors causing and controlling land degradation can be related to two main categories of dynamic environmental parameters, factors related to climate and factors related to population and land use. In this chapter the relationships between climatic factors on the one hand and population and land use on the other will be scrutinized.

As has been demonstrated in Chapter 7, the rainfall conditions in Northern Kordofan were very unfavourable during the Sahelian drought, 1968 - 1974, and accordingly the productivity of agricultural crops was very low. However, the province was not affected by food shortage. But the food situation became precarious after very low rainfall during the summer 1983. Emergency food requests were sent to the UN in January 1984 from the Darfur and Kordofan provinces.

In the Northern Kordofan province the crop failure was very severe and evident during the field work period in February - March 1984. The millet yield in 1983 was estimated at 21 kg/feddan, see Tab. VIII.1, through interviews, and by the official statistics to 56 Kg/feddan. The Kordofan Governor estimated the affected area at 200 000 sqkm, and the number of people affected at 1.8 million. Areas with especially severe food shortage were Sodiri, Bara, En Nahud and Umm Ruwaba regions (Darrag 1984). Most of the nomadic people had migrated to Southern Kordofan. According to the estimates, 530 000 inhabitants still remained in the affected areas, and were in immediate need of food aid (ibid.).

The situation became even worse after the rainy season in 1984. The crop yield was estimated at zero (Ahlcrona 1984).

In the interview results it is impossible to find any consistent trend of lower yield in the northern villages than in the villages further south.

Tab. VIII.1. Summary of interview answers in February - March 1984. People in 32 villages were interviewed concerning inhabitants, percentage outmigrated people, yield of millet in 1983-84 and a normal year, actual price of millet and sorghum, availability of seeds for the next season and if they collect gum arabic.

village name	lat.	lon.	inh.	migr. %	yield 83	norm	price mil. sor.	seed	gum
Gabra es Sheikh	14.33	30.46	4000	60	0	2	60	--	no
Hasabaya	14.29	31.59	450	55	<0.5	4.5	no	28	no
Al Dihair	14.04	32.03	150	37	<0.5	5	no	28	no
Umm Gezira	13.56	30.25	500	4	0.3	2	67	--	no
Umm Damm	13.45	30.59	5000	8	0.3	2	60	32	yes
Umm Sheeba	13.43	30.52	570	18	<1	4.5	60	32	some
Umm Aod	13.33	32.07	2000	75	<1	4.5	no	27	yes
Barakh	13.30	30.37	3000	7	0.3	3	--	38	some
Kerow	13.29	31.26	670	9	<1	5.5	no	35	no
Sungikei	13.26	30.32	1000	10	1	2	--	35	some
Kagarat	13.25	30.43	1000	10	1	7.5	60	--	yes
Baashom	13.25	31.18	1800	20	1	5	45	30	yes
Wad et Tair	13.23	30.29	250	16	<1	2	56	--	no
Ghubeish	13.21	31.20	4000	2	1	3	56	42	yes
Umm Shagaun	13.20	31.41	3000	6	<1	5	45	30	yes
Kabura Abdel Habi	13.18	31.26	1000	10	<1	4.5	56	38	no
Umm Shub	13.16	32.05	890	7	3	4.5	no	25	yes
Rou Rou	13.16	31.23	600	67	0.3	3.5	no	28	yes
Bint Goda	13.16	31.29	3000	17	<1	3	57	35	yes
Al Haraiz	13.16	31.38	650	38	1	7.5	--	--	yes
Abu Gindia	13.14	31.25	280	64	3	6	56	28	yes
El Danga	13.12	31.44	1500	32	<1	4.5	60	35	no
Wad Bilaibli	13.06	31.51	345	29	2	5	no	30	yes
Kaddada	13.04	30.49	1700	9	<1	5	53	35	no
Umm Riswa	13.03	30.14	300	10	<1	1.5	60	38	yes
Abu Rukba	12.56	32.00	20000	10	<1	8	no	26	yes
Umm Shokaba	12.55	31.50	700	29	<1	2	40	28	yes
Umm Sereiha	12.52	30.55	1500	10	1	3.5	45	--	yes
Gaier el Aood	12.49	30.40	1000	30	<1	3	53	38	no
Atabaldia	12.43	30.46	550	5	0	3	--	--	no
El Dugga	12.36	32.07	2000	28	0.3	7	no	--	no
Average				25	0.8	4.2	55	32	

yield of millet in sacks/mukhammas (1 s/m = 123 kg/ha)
prices are in Sudanse pounds (1 SL = 1.8 US\$) per sack (90 kg)

2. SETTLEMENT PATTERN AND ITS IMPLICATION FOR FOOD PRODUCTION IN THE STUDY AREA

Inventory of villages and population estimates were described in Chapter 4. In Chapter 6 several methods for description and analysis of settlement patterns were accounted for. In combination with the statistical analysis of relationships between climate and crop yield in Chapter 7, the spatial models can be used for studies of the spatial pattern of food production.

A linear regression between mean number of days of rainfall at a number of stations and millet yield resulted in a very high degree of explanation, $R^2 = 69\%$ ($r = 0.83$ 0.05).

$$\text{YIELD} = 8 * \text{Number of days with at least 1 mm rainfall}$$

A multiple regression model between millet yield as the response variable, and average number of days with at least 1 mm of rainfall and average amount of rainfall (June - September) measured in En Nahud, Er Rahad, Umm Ruwaba and El Obeid, as explanatory variables resulted in the following relationship ($r = 0.84$ 0.05):

$$\text{YIELD} = -271 + 22.6 * \text{Days} - 0.271 * \text{Rainfall}$$

(where yield is expressed in Kg/feddan) which is slightly stronger, $R^2 = 71\%$, though not significantly. The observed and the predicted millet yields are presented in Fig. 8.1.

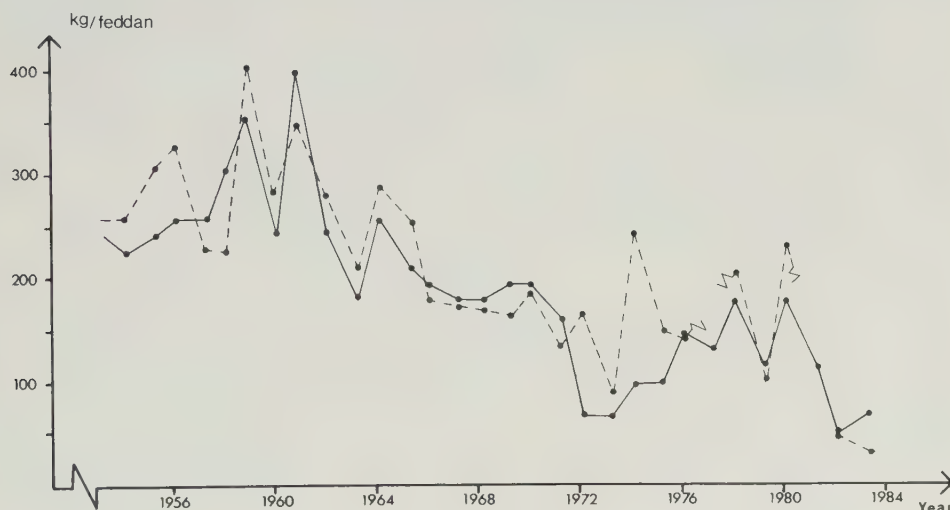


Fig. 8.1. Diagram showing the observed millet yield (Dept. agricultural statistics) as solid line and the predicted millet yield as dashed line.

The fallow/cultivation cycle has been investigated through interviews during field work and several authors have presented figures on the length of fallow and cultivation periods (cf. Chapter 6). The length of the periods vary substantially over the province. Olsson K. (1984a) proposed a rough average to be 6 years fallow period and 5 years cultivation period. This implies that only 45 % of the area available can be used for cultivation in one year. Reeves & Frankenberger (1982) reported that on average 53 % of the land available to villagers was cultivated.

The minimum grain requirement is defined as 0.43 kg/capita/day (USDA 1984), i.e. 156 Kg/capita per year. In addition to per capita consumption requirement the amount of seed for next season must be included. Reeves & Frankenberger (1982) estimated the seed requirement at approximately 3 kg/feddan (equal 7 kg/Ha).

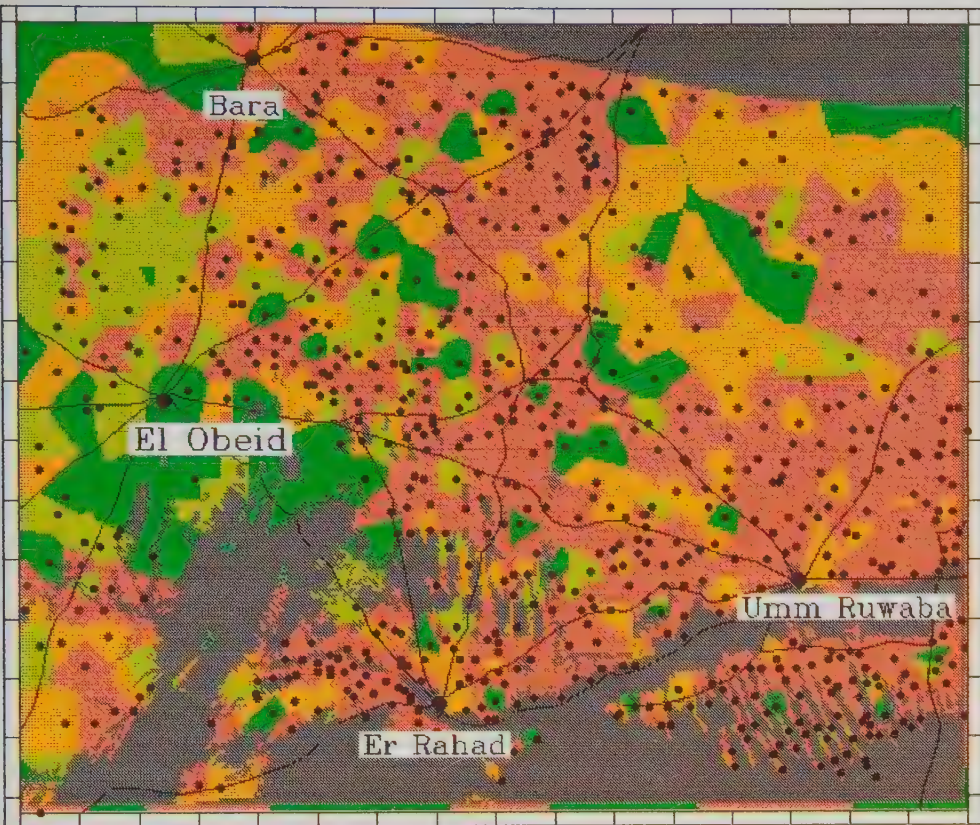
In the land availability map presented in Figs. 6.15 and 6.16, the number of hectares per capita is shown. If this map is multiplied by the productivity of a good year, e.g. 1961 (952 kg/hectar), we can study the spatial pattern of potential per capita production, see Fig 8.2.

The average yield reported by the villagers, presented in Tab. VIII.1, was 276 kg/hectar. If we use the land availability map and assume this productivity, we can see the proportion of the totally available land area that must be cultivated to meet the minimum annual requirement of grain, Fig. 8.3. We can see that only in very limited areas have the people possibilities to maintain the traditional fallow periods of 15 to 20 years.

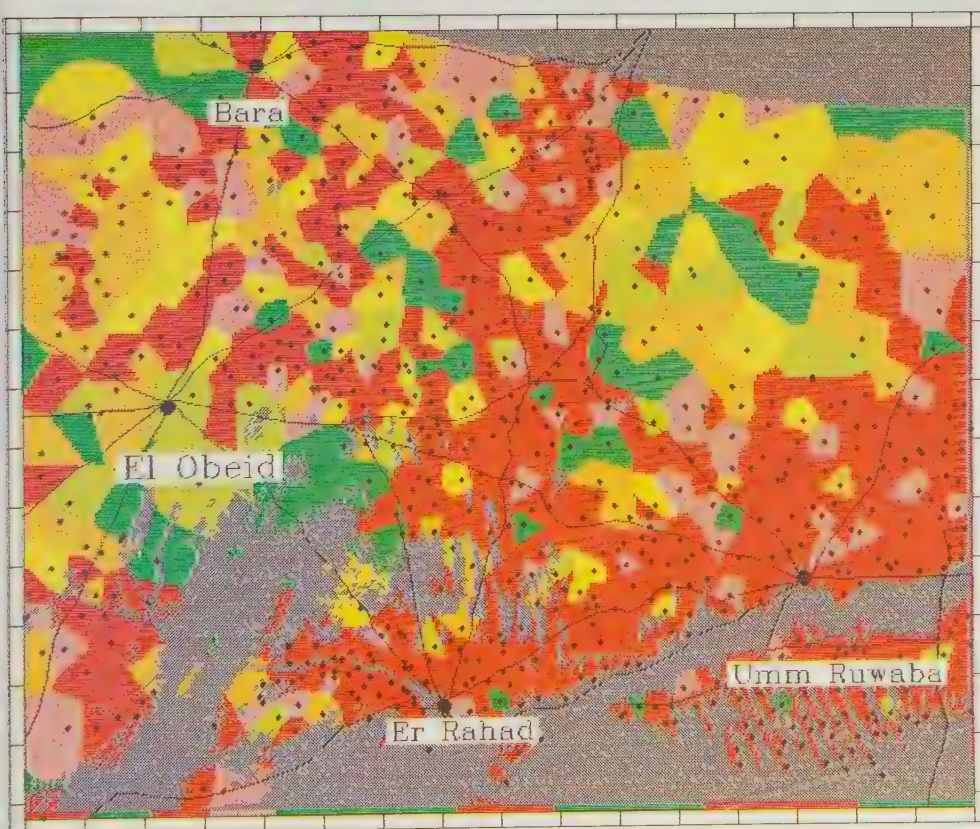
However, it is very unlikely that the productivity is uniform over the study area. The climatological data presented in Chapter 7 indicate that a strong trend from north to south exists in the rainfall pattern. The regression equation above can be used to calculate the average productivity at the different stations. A fifth degree polynomial function was then used in order to fit a smooth surface describing the productivity in the study area. This is presented in Fig. 8.4.

According to Reeves & Frankenberger (1982), the average cultivation area was 13 Ha per family. The land availability model gives a median value of 3 Ha per capita. The average household size is 7.6 (Watson et al 1976 and Reeves & Frankenberger 1982), which means that according to the land availability model, the median value of land availability is 23 Ha per household. Roughly 50 % of the available land area is cultivated and accordingly, the land availability model ends up with a median cultivation area per household of 12 Ha, which corresponds very well with the figure 13 Ha presented above.

To meet the minimum grain requirement of 156 kg per capita the productivity for an average household (12 ha) must be at least 100 kg/ha or 41 kg/feddan. In the diagram in Fig. 8.1 we can



8.2



8.3

Fig. 8.2. The potential per capita production of millet, assuming a productivity of 400 Kg/feddan (952 Kg/ha). The colour scale corresponds to: 1 = areas excluded from cultivation, 2 = up to 1000 kg, 3 = 1000 - 2500 kg, 4 = 2500 - 5000 kg and 5 = over 5000 kg.

Fig. 8.3. The percentage of the land that must be cultivated to fill the minum grain requirement, assuming the average productivity of 276 kg/hectar. The colour scale corresponds to: 1 = over 75 %, 2 = 75% - 50%, 3 = 50% - 30%, 4 = 30% - 20%, 5 = 20% - 10% and 6 = under 10 % and excluded areas.

Scale: Interval between tickmarks correspond to 10 km.

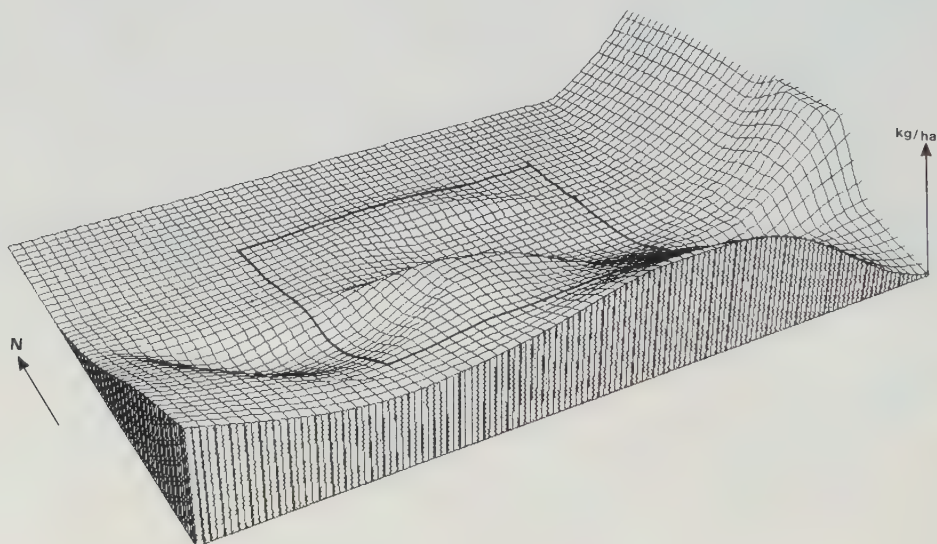


Fig. 8.4. Three dimensional plot of the trend surface describing productivity in a rectangle from Lat. 12 to 16 and Long. 28 to 33. The frame indicates the study area.

see that the productivity during the Sahelian drought, especially 1972 and 1973, was slightly above this limit. In 1983, according to estimates in N. Kordofan (Olsson 1984b), the productivity was 50 % below this limit, with food shortage as a result.

What makes the situation very risky from a food supply point of view is that the settlement pattern is not adequately adapted to the productivity trend, shown in Fig. 8.4. An analysis of variance between number of hectares per capita and geographical northing shows a fairly consistent tendency of more land the more north the village is situated, see Fig. 8.5.

However, the difference between land availability in the northern part and in the southern part does not compensate enough for the large difference in expected productivity. Tab. 8.2 gives figures on average land availability, expected productivity according to the regression model and the probability (according to a normal distribution) of satisfying the minimum grain requirement (42 kg/feddan) for the average land availability of 12 ha/capita.

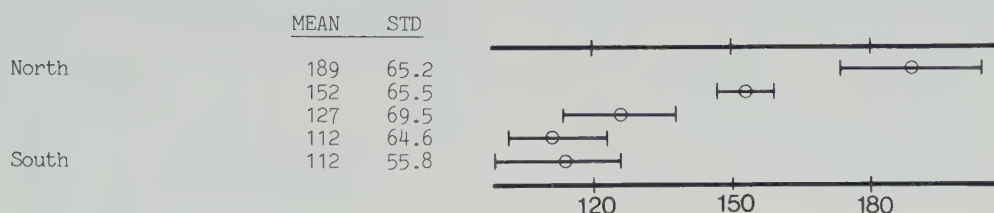


Fig. 8.5. Result from analysis of variance between number of hectares per capita in villages and the geographical north position.

Tab. VIII.2 Average land availability, expected productivity and probability of satisfying the minimum grain requirement for three regions in the study area.

	median land availability (Ha/household)	expected productivity (Kg/feddan)	probability (%)
BARA	19.7	77	47
UMM RUWABA	14.9	174	80
EL OBEID	16.0	300	89

If the land availability map is combined with the trend surface describing the expected average productivity, a detailed map of the spatial pattern of supply and demand of grain can be achieved, see Fig. 8.6. A zone of low per capita production crosses the study area from NW to SE. The area in the NE part of the image shows fairly high per capita production in spite of the low expected productivity. The El Obeid area has got favourable conditions, high productivity and rather low population intensity, as expressed by the land availability model.

The map in Fig. 8.6 gives us information on what areas are most likely to suffer from crop failure. It can however not represent any real situation but only a theoretical average situation.

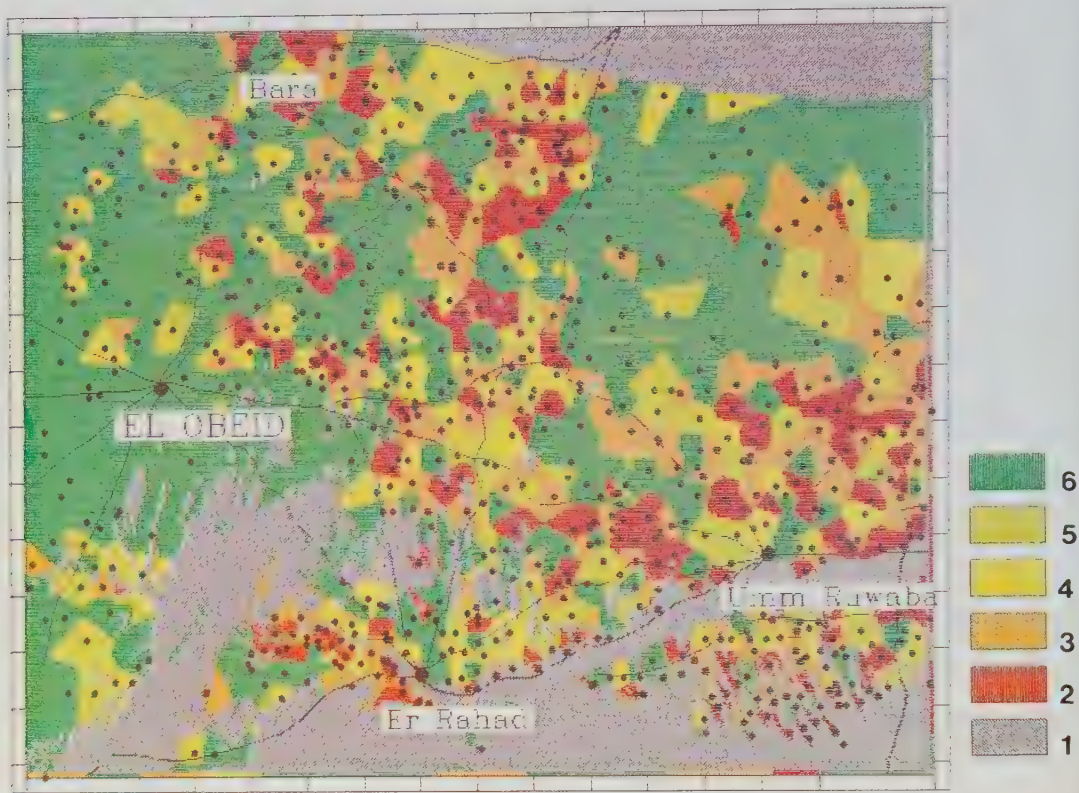


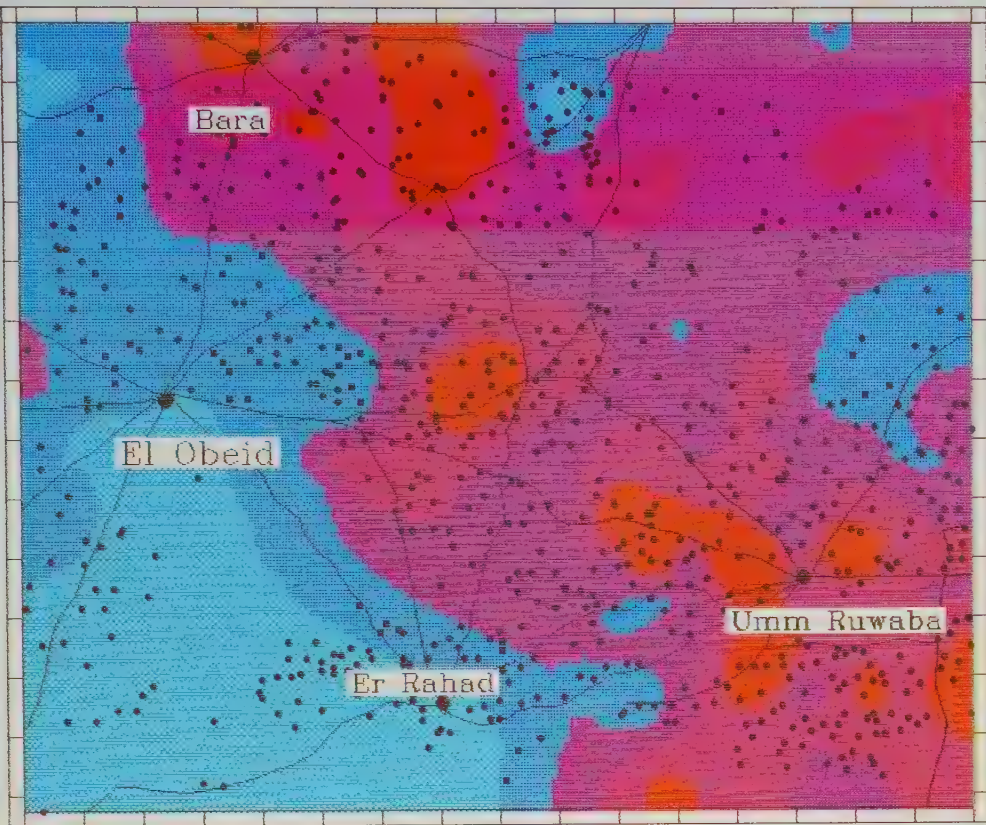
Fig. 8.6. Combination of land availability (hectars/capita) and the trend surface showing expected productivity. The map shows potential per family production of millet, assuming that 50 % of the available land is cultivated. The colour scale corresponds to: 1 = excluded areas, 2 = under 2000 kg, 3 = 2000 - 4000 kg, 4 = 4000 - 6000 kg, 5 = 6000 - 8000 kg and 6 = over 8000 kg.

Scale: Interval between tickmarks correspond to 10 km.

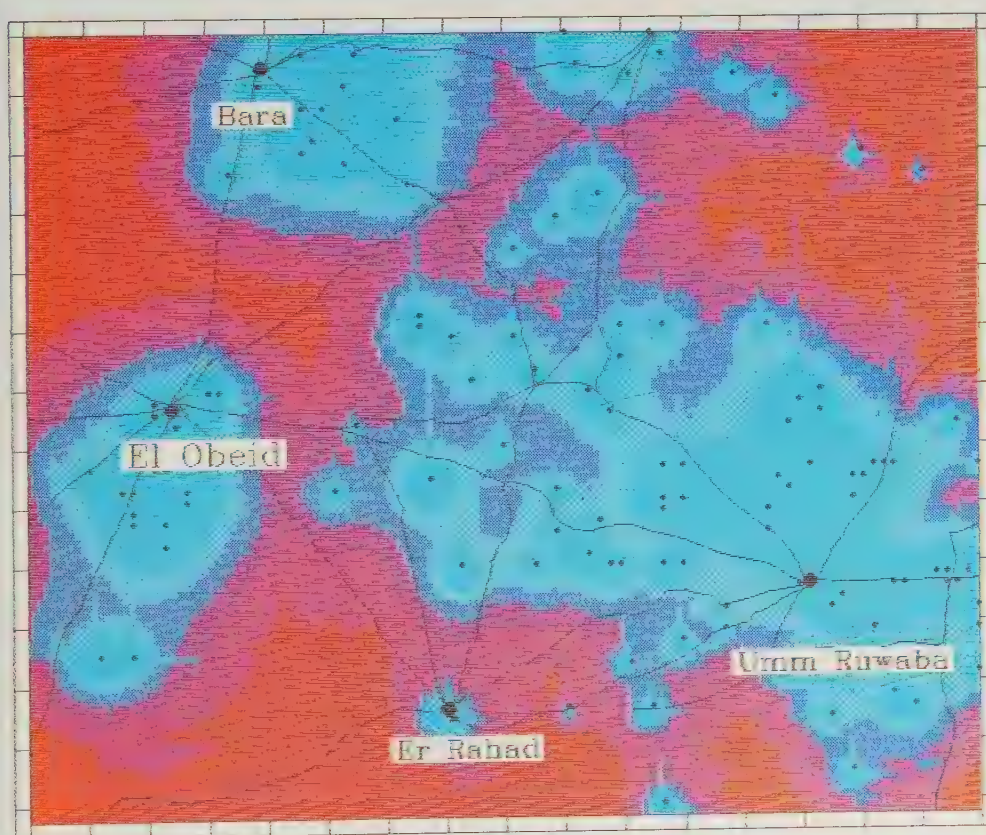
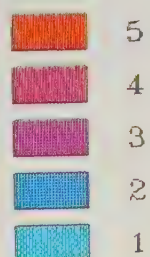
on. As has been mentioned in Chapter 7, the spatial variation of the rainfall does not permit any interpolation of data, from the rather sparse network of recording stations, for one specific year.

If the productivity can be estimated by either a much denser network of rainfall stations, or by means of satellite data (see e.g. Hellden 1984 & 1985), the principle of combining land availability and productivity will be a very powerful methodology for e.g. estimating number of people affected by crop failure. From the land availability model it is possible to go back to the original table data, showing the number of inhabitants for each of the affected villages.

The per capita production figures shown in Fig. 8.6 can be used



8.9



8.10



Fig. 8.9. Depth of the wells in feet (data from Rural Water Corporation, El Obeid). The map is generated by interpolation of the figures on depth of the wells in Fig. 8.7. The colour scale corresponds to: 1 = below 200 ft, 2 = 200 - 400 ft, 3 = 400 - 600 ft, 4 = 600 - 800 ft and 5 = over 800 ft.

Fig. 8.10. Capacity of wells, expressed as discharge in gallons per hour during 3 days of test pumping (data from Rural Water Corporation, El Obeid). The map is generated as a potential model based on 10 neighbours and a distance factor of 1.5. The colour scale corresponds to: 1 = below 50 gal/hr, 2 = 50 - 100 gal/hr, 3 = 100 - 200, 4 = 200 - 400 and 5 = over 400.

Scale: Interval between tickmarks correspond to 10 km.

in order to estimate how close to the subsistence level different areas are. If the negative trend in number of rainfall days (Fig. 7.5 and Tab. 7.3) persists, the risk of severe and frequent crop failures are to be expected. In Fig 8.7 a diagram giving a graphical representation of the present and predicted food supply situation of three different regions within the study area.

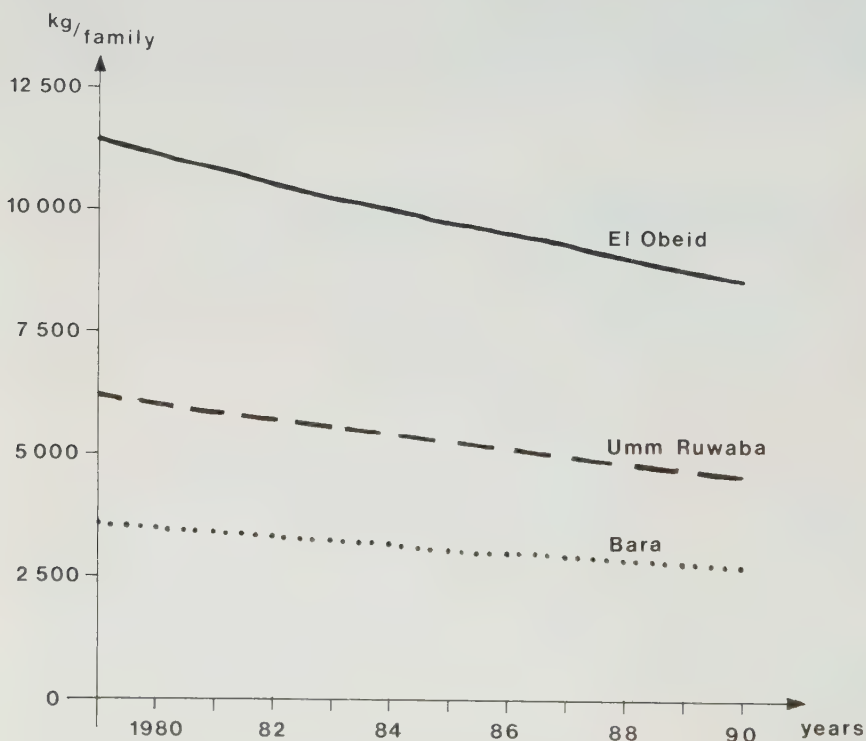


Fig. 8.7. Potential per family production of millet in three regions of the study area. The diagram starts in 1979, with the land availability based on the 1979 Landsat images, and the expected productivity based on the regression equation between rainfall and yield. The population increase has been assumed to be 2.7 per cent annually.

3. FACTORS INFLUENCING THE SETTLEMENT PATTERN

The settlement pattern in the study area is generally fairly old. According to interviews, many villages were established during the Mahdiya time or early twentieth century. A few, mostly small, villages were established during the 1930s as an extension of another larger village. Reeves & Frankenger (1981) reported on time of establishment of first settlement of 18 villages in the vicinity of El Obeid. Except for two rather small villages, established in 1940, the majority of the villages were established in the early 1900s or earlier.

Along the railway from Kosti to El Obeid many villages were established shortly after the construction in the 1920s. The major towns in the study area have probably been attracting settlements.

One of the most important factors determining the settlement distribution is the ground water conditions. In Fig. 8.7 the distribution of deep-bored wells is shown. Most of the wells are situated in a belt from Umm Ruwaba to Bara.

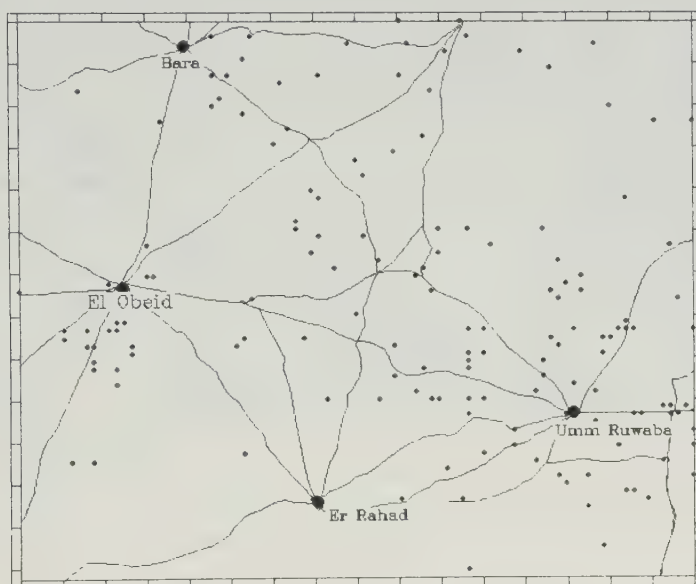


Fig. 8.7. Map showing the position of deep wells in the study area (data from Rural Water Corporation, El Obeid)

The depth and the capacity of wells as well as the quality of the water are other factors influencing the settlement. In Figs. 8.9 and 8.10, the depth of the wells and their capacity are shown. One reason why the area NE of Umm Ruwaba is so densely populated is probably because of the good supply of water and that the ground water table is shallow.

The area around El Obeid, especially to the NW, has poor access to ground water, and accordingly the population pressure is comparatively low.

Another factor important for the settlement pattern is the soil conditions. Rain-fed agriculture of millet can be practised without any mechanized equipment on the sandy Qoz soil. The very poor water holding capacity and the low nutrient status of the soil is to some extent compensated for by the loose structure of the soil, allowing the crops to develop a very fine root system. The more fine-textured soils are generally more fertile, but require much more input of labour and equipment to be successfully cultivated. In Fig. 8.11, the major soil regions and all villages are shown.

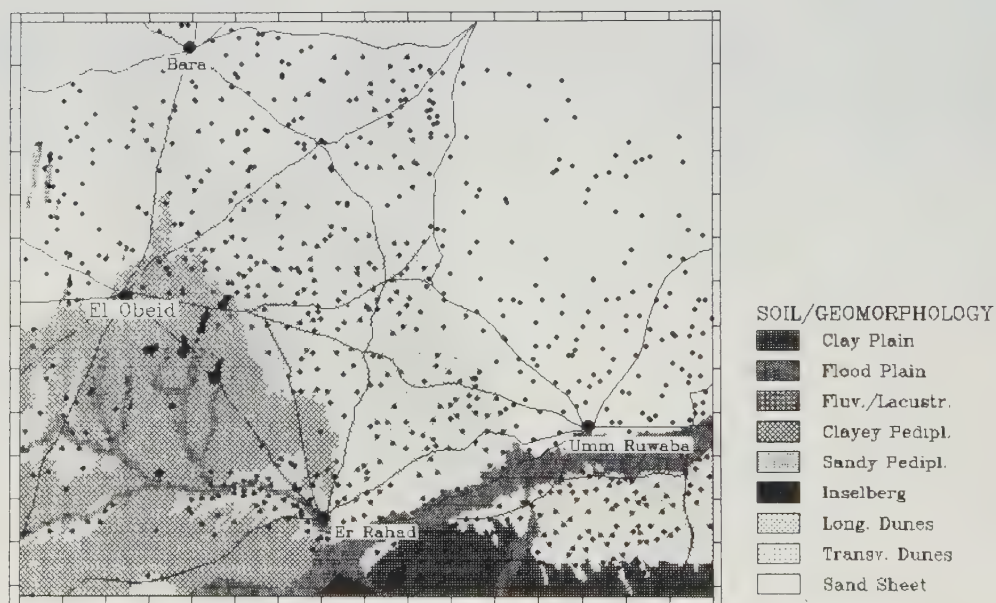


Fig. 8.11. The major soil regions of the study area with all villages plotted (modified from UNDP & FAO 1967)

Scale: Interval between tickmarks correspond to 10 km.

4. CONCLUSION AND DISCUSSION

Drought and famine are two different phenomena. Drought can simply be defined as lack of sufficient precipitation, i.e. a true natural phenomenon. But whether famine, in connection with drought, is a man-made or natural phenomenon has been discussed often. In this chapter we have seen examples of climatical causes of crop failure as well as man-made causes of insufficient per capita crop production.

The agricultural population can cope with drought in different ways, the most obvious ones are:

1. Increase the area under cultivation by expanding into new areas.
2. Intensify the cultivation, without expanding into new areas, i.e. by shortening of fallow periods.
3. Migrate to other areas.

The first way was clearly demonstrated by Hellden (1984). During the Sahelian drought, the total area under cultivation was significantly increased. The second one was most likely very common in the Umm Ruwaba region during the Sahelian drought. The typical "patchwork" pattern was erased by continuous cultivation (see the analysis of texture in Chapter 4 and Fig. 9. 8). This has also been verified through interviews in villages in the area. Both ways of coping with drought require access to more land.

According to interviews in villages, seasonal migration in the winter is a common way of combining agriculture during the rainy season with work in plantations or in industries during the dry season. In 1984, it had however been very common that whole families left the villages, not only for one season but for an indefinite period of time (see Tab. VIII.1). In addition to the percentages outmigrated from the sample villages, presented in Tab. VIII.1, many villages were totally abandoned. Migration of whole families is probably only practised when the conditions are extremely bad.

The focus has been on three parts of the study area, the El Obeid region, the Bara region, and the Umm Ruwaba region. The two latter ones can be regarded as very vulnerable from an agricultural point of view. In the Bara region the climatical conditions are very unfavourable. Although the population pressure is comparatively low and the availability of land better than in other regions, the risk of food shortage is impending. In the Umm Ruwaba region, the climatic prerequisites for agriculture are much more favourable, but are counteracted by the shortage of land. The El Obeid region is in a much more favourable situation. The expected productivity and the probability of receiving enough rain for a good crop yield are both high, and the average land availability is slightly higher than in the Umm Ruwaba region.

It must however be emphasized that the discussion of the balance between productivity on the one hand, as a function of climatic variables, and land availability on the other is very theoretical. It assumes a closed system, without any external influences, and takes only the production of millet into consideration. The land use in the real case is a mixture of, among others, cultivation of different crops, husbandry of different domestic animals and collection of gum arabic.

nine

Synthesis and Conclusion

1. INTRODUCTION

In the previous chapters large quantities of data from different sources have been presented and analysed, raster data as well as vector data. All data have been integrated into a common geographical information system. In this chapter the aim is to combine the previously defined information in an attempt to study the different relationships existing between the data sets.

According to Warren & Maizels (1976), "... the first requirement of a holistic approach to research is that there should be some model of how each component fits into the ecosystem", and further, "any model of a dry ecosystem must be dynamic, for only then can it be used to predict the effects of proposed land use strategies".

A geographical information system containing relevant data will substantially facilitate any modelling attempts, over time as well as in space. However, any "desertification model" based on a single indicator of desertification as dependent variable and a number of environmental variables as independent ones in a multiple regression equation, as suggested by Hellden (1981) is probably very unlikely. Desertification, if such a process exist and can be defined at all, is such a complex process that a single indicator will not be adequate to represent the great number of interrelated components.

Modelling of environmental processes is however a very important tool, maybe not for formulation of highly complex models involving a wide range of different variables, but "micro models", i.e. simple models involving few input variables, may be an efficient way of generating relevant data for research on more complex systems. Examples of models describing and predicting nomadic herd sizes were presented by Dahl & Hjort (1976). Modelling of biological productivity, as a function of soil and climatic parameters, has been carried out by several authors, e.g. Breman & deWit (1983).

Remotely sensed data contain a very large amount of information about both human and natural conditions. Biological production, expressed as amount of biomass at the time of recording of the

data, can fairly accurately be measured. Land use pattern, expressed as image patchiness, is an example of cultural features that can be measured.

Three landscape regions have been selected for the analysis of relationships between cultural and natural conditions (see Fig. 9.1). The areas have been chosen so that the soil conditions are more or less uniform. It is therefore possible to compare the three areas regarding albedo and biomass.

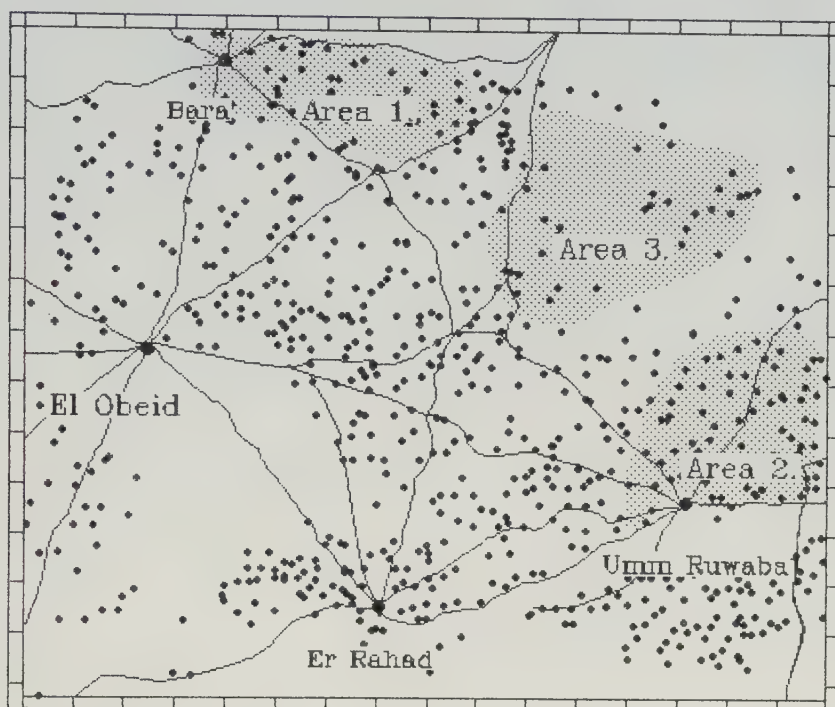


Fig. 9.1. Map showing the three test areas used for statistical analyses

The Bara region is an example of a region with rather intensive land use, but unfavourable climatic conditions. It is situated north of the traditionally defined agronomic dry boundary (see section 7.4), but on the other hand belonging to the old agricultural core area according to Born (1965).

The Umm Ruwaba region is an example of extremely intensive land use near the agronomic dry boundary. The region was however considered as being outside the 19th century agricultural core area.

A region between Umm Ruwaba and Bara has been taken as an example of low land use intensity, outside the agricultural core area.

A summary of the mean pixel values and standard deviation for the three areas is presented in Tab. IX.1.

It is interesting to see that the Bara and the Umm Ruwaba regions both had equally very high albedo values, in spite of the difference in rainfall. In 1979, the Umm Ruwaba area had lower albedo than the Bara area, indicating a recovery of the vegetation. The same tendency can be seen concerning the biomass.

Tab IX.1 Descriptive statistics for the three test areas

	BARA		UMM RUWABA		IN BETWEEN	
	(mean)	(std)	(mean)	(std)	(mean)	(std)
POPULATION POTENTIAL	51.9	35.9	66.2	37.3	18.5	11.5
LAND AVAILABILITY	19.1	47.6	9.2	28.1	31.4	36.1
DISTANCE TO VILLAGE	41.4	22.5	42.1	22.2	81.8	44.9
RAINFALL (MM)	257.6	10.8	328.6	19.0	283.6	16.2
No. OF DAYS 1 MM	18.6	1.0	21.4	1.6	18.5	1.2
ALBEDO JAN. 1973	32.4	3.4	32.7	3.6	29.1	3.2
ALBEDO JAN. 1979	23.6	2.6	21.2	2.6	21.1	2.4
ALBEDO MARCH 1979	30.1	2.9	26.1	2.4	26.5	2.1
ALBEDO SEPT. 1979	25.6	3.7	24.7	3.4	21.3	3.0
BIOMASS JAN. 1973	100.7	2.5	99.9	2.5	98.4	3.0
BIOMASS JAN. 1979	105.9	3.0	108.4	3.7	107.6	4.5
BIOMASS MARCH 1979	92.2	2.0	92.8	2.4	92.2	2.8
BIOMASS SEPT. 1979	105.1	6.2	103.8	7.4	108.5	6.6

Rainfall figures for June - September.

2. RELATIONSHIPS BETWEEN POPULATION PRESSURE, BIOMASS AND ALBEDO

There are several reasons to anticipate the amount of biomass in a region with very high population pressure to be different from that of a sparsely populated region. One is that the large amount of people and livestock consume a lot of biomass. Another may be that the high intensity of land use has lowered the productivity of the soil.

Many of the causes of desertification are assumed to be related to population parameters. Kates et. al (1976) wrote "... desertification usually arises from two sets of imbalances in the human use of dry lands: (1) those related to population growth, decline and movement, and (2) those related to the introduction or abuse of technologies, or new land uses and

economic ties". It is plausible to assume that the size of a village does influence the conditions in the vicinity of the village. Several authors, e.g. Born (1965), Hammer-Digernes (1977), Rapp (1978) and Rapp & Hellden (1979), have stressed the importance of degraded village and water point perimeters as a desertification process. Ibrahim (1979) stated that it was possible, through satellite images to prove that desert expansion proceeds by expansion of desertified perimeters of permanent settlements. "Especially in the perimeters of settlements and water points overstocking damages are most conspicuous. They render it easy to recognize the location of settlements with water points on the Landsat imagery, on which they appear as white patches" (Ibrahim 1984). Hellden (1984) investigated the size of degraded village perimeters around 77 villages NW of El Obeid in air photos from 1962 and Landsat images from 1973 and 1979. It was impossible to find any systematic change in the size of the perimeters. Only 7 of the studied perimeters had increased (95% significant) in size. However, The village perimeters visible in Landsat images, are confined to the immediate outskirts of villages, typically 200 - 500 m.

In order to test the relevance of these hypotheses, statistical analyses of the relationships between biomass and albedo on the one hand, and different population parameters on the other, were carried out. The correlation coefficients are tabulated in Tabs. IX.2 - IX.4.

Tab. IX.2 Correlation between population potential and image transformations

	UMM RUWABA	BARA	CENTRAL	ENTIRE GOZ
ALBEDO JANUARY 1973:	0.50 X	0.00	0.10	0.30 x
ALBEDO JANUARY 1979:	0.17	0.03	0.08	0.15
ALBEDO MARCH 1979:	0.22 x	0.05	0.13	0.17
ALBEDO SEPTEMBER 1979:	0.38 X	0.03	0.12	0.22 x
BIOMASS JANUARY 1973:	0.18	0.18	0.01	0.20 x
BIOMASS JANUARY 1979:	-0.19	0.06	0.01	0.05
BIOMASS MARCH 1979:	-0.12	0.05	0.08	0.09
BIOMASS SEPTEMBER 1979:	-0.15	0.16	-0.02	-0.04

X = correlation coefficient over 0.3

x = correlation coefficient between 0.2 and 0.3

The correlation coefficients are mostly very low, with some interesting exceptions.

Albedo 1973 was the image that was highest correlated to any of the population parameters. As has been shown by several authors (see Chapter 4), high albedo can be related to overexploitation of the soil, provided that the soil has high albedo in itself, like the Qoz sand. In the Umm Ruwaba area, the correlation between albedo 1973, during an extremely dry period, and

TAB IX.3 Correlation between distance to village and image transformations

	UMM RUWABA	BARA	CENTRAL
ALBEDO JANUARY 1973:	-0.21 x	-0.11	-0.07
ALBEDO JANUARY 1979:	-0.10	-0.20 x	-0.02
ALBEDO MARCH 1979:	-0.16	-0.23 x	-0.05
ALBEDO SEPTEMBER 1979:	-0.18	-0.17	-0.23 x
BIOMASS JANUARY 1973:	-0.09	-0.08	-0.18
BIOMASS JANUARY 1979:	0.07	0.11	-0.12
BIOMASS MARCH 1979:	0.03	0.05	-0.09
BIOMASS SEPTEMBER 1979:	0.11	0.08	-0.08

X = correlation coefficient over 0.3

x = correlation coefficient between 0.2 and 0.3

TAB IX.4 Correlation between land availability (ha/capita) and image transformations

	UMM RUWABA	BARA	CENTRAL
ALBEDO JANUARY 1973:	-0.25 X	0.09	-0.07
ALBEDO JANUARY 1979:	-0.06	0.03	-0.09
ALBEDO MARCH 1979:	-0.05	0.04	-0.09
ALBEDO SEPTEMBER 1979:	-0.14	0.02	-0.04
BIOMASS JANUARY 1973:	-0.12	-0.04	-0.05
BIOMASS JANUARY 1979:	-0.04	-0.06	0.06
BIOMASS MARCH 1979:	-0.05	-0.05	-0.01
BIOMASS SEPTEMBER 1979:	0.10	-0.14	0.00

X = correlation coefficient over 0.3

x = correlation coefficient between 0.2 and 0.3

population parameters was 0.5, i.e. 25 % of the albedo variations could be explained by the population potential. The other areas showed however no correlation at all. The conclusion is, that only in cases of extremely high population pressure, is it possible to find a direct relationship between the people's exploitation of the land and surface albedo.

The fact that only the 1973 albedo was highly correlated to population pressure, may indicate that the overexploitation of the land is only evident during periods of drought. When the climatical conditions are more favourable, the productivity of the soil is sufficient for sustained production of crops and natural vegetation.

The correlation was higher between population potential and albedo, than it was between the other two parameters and albedo. This indicates that the assumption behind the potential model is sound, i.e. that both the size of a population centre and the distance to it are of importance.

The biomass was not significantly correlated to the population parameter. A problem is here that the 1973 data were not appropriate for biomass transformation. Another conclusion from this is that the albedo is a more sensitive transformation than is the biomass. Since the biomass transformation is based on two bands only, the information content is less than in the albedo transformation, based on all four bands.

3. ANALYSIS OF CHANGES IN THE LANDSCAPE

In order to investigate the impact of population parameters on the changes in the landscape over time, a number of temporal differences of the image transformations were generated, see Chapter 4, from January 1973 to January 1979, from January 1979 to March 1979 and from March 1979 to September 1979. These maps are presented in Figs. 9.2 - 9.8. The biomass transformations are, however, not as useful as the albedo ones, since their information content is very limited in a dry season image. The result from correlation analyses between changes in albedo and biomass, and population parameters are presented in Tabs. IX.5 - IX. 7.

TAB IX:5 Correlation between population potential and changes in albedo and biomass between 1973 and 1979

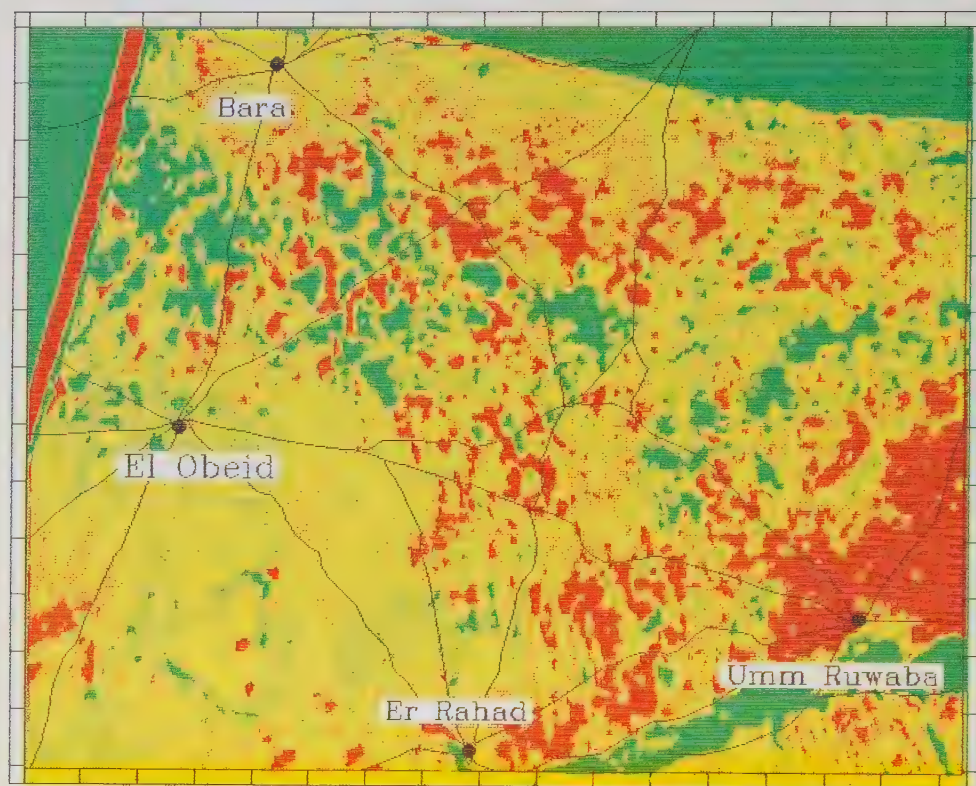
	UMM RUWABA	BARA	CENTRAL	ENTIRE GOZ
ALBEDO JAN 73 - JAN 79:	0.11	0.01	-0.07	0.06
ALBEDO JAN 79 - MAR 79:	-0.07	-0.02	-0.07	-0.02
ALBEDO MAR 79 - SEP 79:	-0.24 x	-0.10	-0.02	-0.11
BIOMASS JAN 73 - JAN 79:	0.26 X	0.07	0.17	0.13
BIOMASS JAN 79 - MAR 79:	-0.12	0.03	-0.04	0.01
BIOMASS MAR 79 - SEP 79:	0.11	-0.15	0.05	0.06

X = correlation coefficient over 0.3

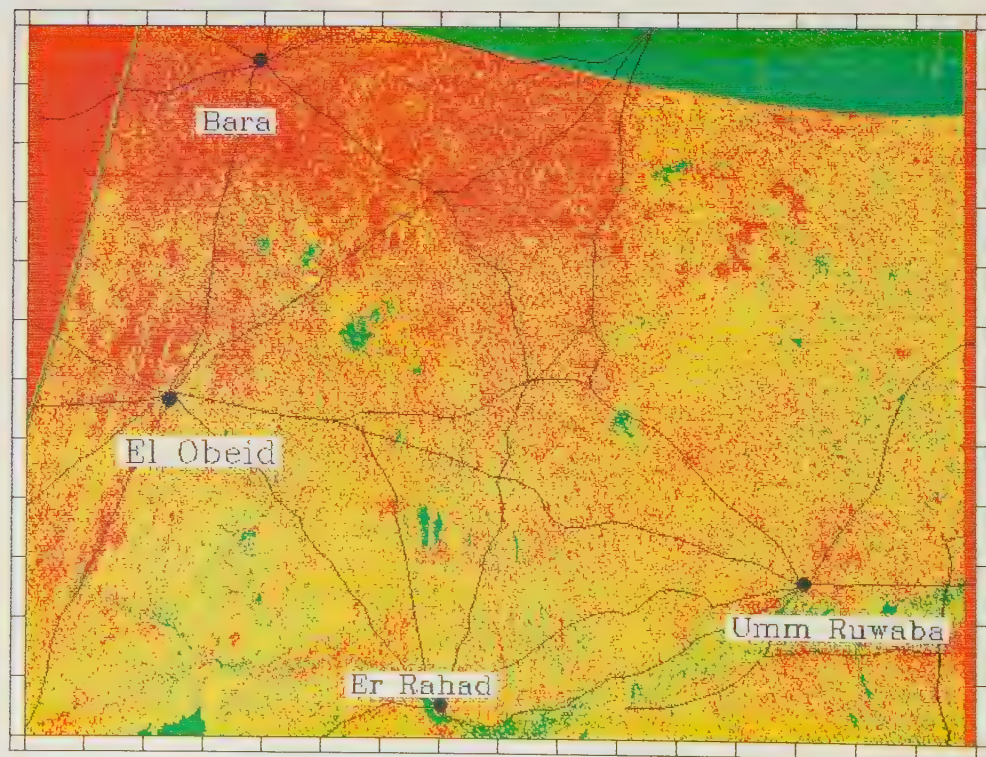
x = correlation coefficient between 0.2 and 0.3

TAB IX:6 Correlation between distance to village and changes in albedo and biomass between 1973 and 1979

	UMM RUWABA	BARA	CENTRAL
ALBEDO JAN 73 - JAN 79:	-0.01	0.06	0.01
ALBEDO JAN 79 - MAR 79:	0.08	0.08	0.04
ALBEDO MAR 79 - SEP 79:	0.08	-0.02	-0.06
BIOMASS JAN 73 - JAN 79:	-0.10	-0.14	-0.03
BIOMASS JAN 79 - MAR 79:	0.05	-0.08	-0.06
BIOMASS MAR 79 - SEP 79:	-0.09	-0.07	0.05



9.3



9.4

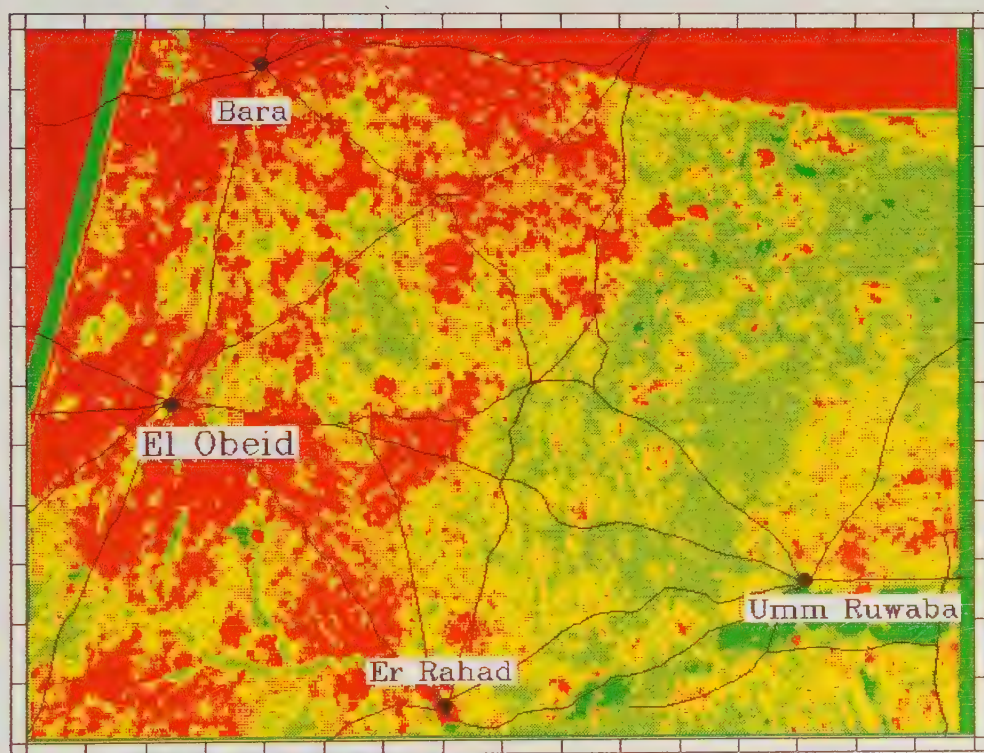
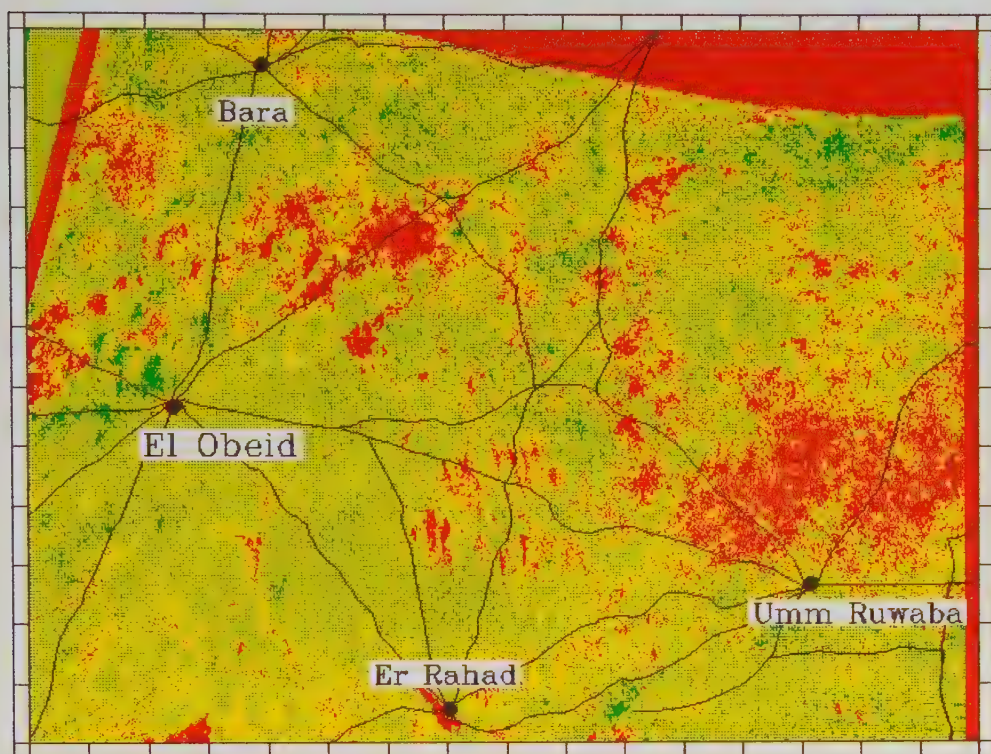


Fig. 9.3. Albedo difference image January 1973 to January 1979. Only very local regions showed increased albedo in 1979 compared to 1973. The most striking feature of the change image is the substantial decrease in albedo in the region NE of Umm Ruwaba. The very sparsely populated region in the SW part of the image show a moderate decrease in albedo. The colour scale corresponds to: 1 = no change, 2 = decrease less than 6 units, 3 = decrease 6 - 8 units, 4 = decrease 8 - 10 units and 5 = decrease more than 10 units.

Fig. 9.4. Albedo difference image January 1979 to March 1979. Most of the image show no or less than 7 % increase in albedo. But the Bara region increased much more in albedo than other areas within the Qoz region. The colour scale corresponds to: 1 = increase more than 7 units, 2 = increase 5 - 7 units, 3 = increase 3 - 5 units, 4 = increase 1 - 3 units and 5 = no change.

Fig. 9.5. Albedo difference image March 1979 to September 1979. After the rainy season we can expect a general decrease in albedo. In this image the Umm Ruwaba region shows the least change. The Bara region does not show any special features. The colour scale corresponds to: 1 = decrease more than 10 units, 2 = decrease 5 - 10 units, 3 = decrease 0 - 5 units and 4 = no change or slight increase.

Fig. 9.6 Biomass difference image January 1973 to January 1979. Most of the area showed increased biomass values, especially in the western part. Also in the Umm Ruwaba area we can see increased values. The colour scale corresponds to: 1 = no change, 2 = increase less than 20 units, 3 = increase 20 - 25 units, 4 = increase 25 - 30 units, 5 = increase 30 - 35 units and 6 = increase more than 35 units.

Scale: Interval between tickmarks correspond to 10 km.

TAB IX:7 Correlation between land availability and changes in albedo and biomass between 1973 and 1979

	UMM RUWABA	BARA	CENTRAL
ALBEDO JAN 73 - JAN 79:	-0.07	0.05	0.05
ALBEDO JAN 79 - MAR 79:	-0.02	-0.02	0.00
ALBEDO MAR 79 - SEP 79:	0.11	0.00	-0.03
BIOMASS JAN 73 - JAN 79:	-0.02	0.02	-0.08
BIOMASS JAN 79 - MAR 79:	-0.01	-0.03	0.07
BIOMASS MAR 79 - SEP 79:	-0.11	0.13	0.00

3.1 Changes from 1973 to 1979

In Fig 9.2 we can see a fairly distinct pattern of albedo changes from January 1973 to January 1979, i.e. changes from an extremely dry period to a more normal situation. The albedo generally decreased substantially, probably due to recovery of the vegetation. In Figs. 4.21 and 4.22, we can see that the overall change was from 29 % to 21 %. The most drastic change took place in the most densely populated region N and NE of Umm Ruwaba. A vast area decreased over 10 percent in albedo. In 1973, this area was considered the most severely degraded one in the whole province (Khogali 1980). In the Landsat image from 1973, e.g. Fig 4.17 this area is very striking with e.g. albedo values well above 35 %. In January 1979, the same area did not show higher albedo values than other comparable areas in the Qoz region.

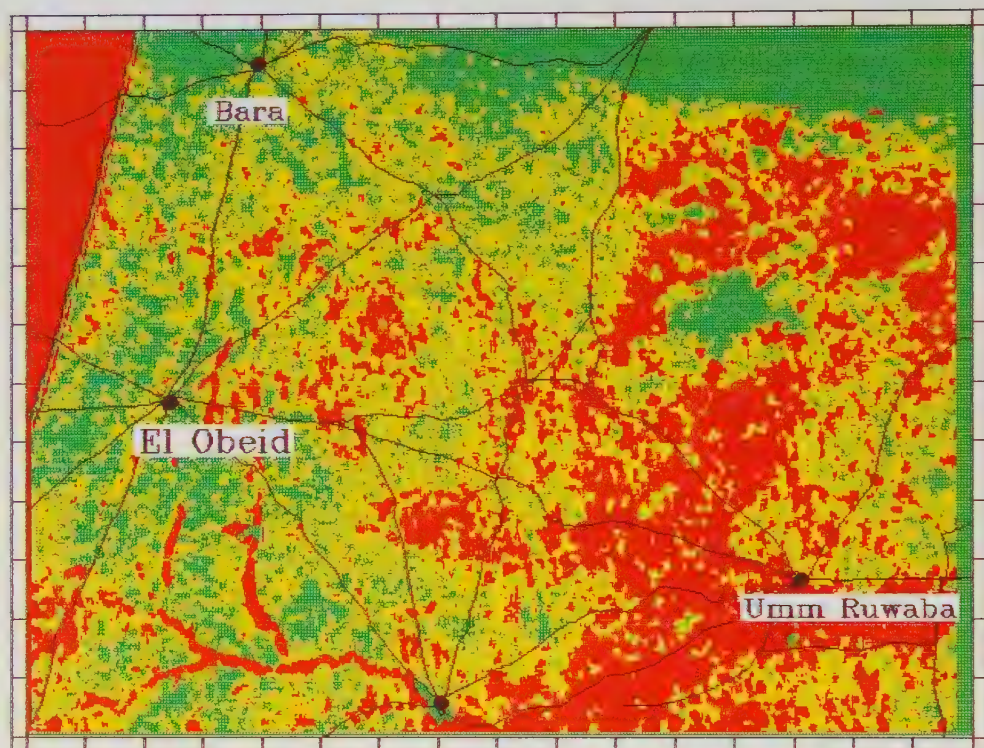
The conditions in this area continued probably to improve. During field work in January - February 1980, it was especially noted that the whole area between Er Rahad and Umm Ruwaba lacked trees of *Acacia senegal*. During field work in the same region in 1982 and 1984, it was evident that the *Acacia senegal* trees had recovered substantially. This was also expressed by Khogali (1983).

Another important change from 1973 to 1979 is in textural properties, see Figs. 4.29 - 4.31 and 9.9. In 1973, the whole area was very homogeneous with very high albedo values. The cultivation pattern was totally erased. In 1979, the texture had increased significantly, indicating that the cultivation pattern had returned.

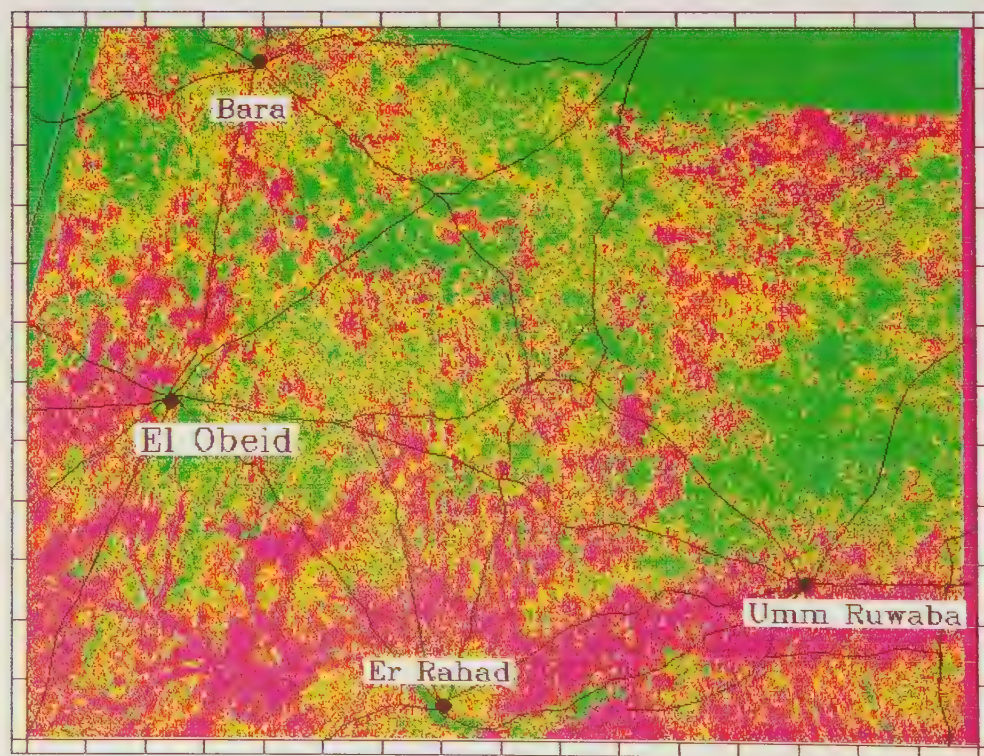
Other areas with substantial decreases in albedo were dune ridges south of Khor Abu Hahl and between Er Rahad and Umm Ruwaba, which were intensively cultivated. In the northern part of the study area, we can see major decreases in albedo east of Bara, indicating improved environmental conditions.

The large and very sparsely populated area of fine textured soils in the southwestern part of the study area, showed a weak but consistent decrease in albedo. The reason is probably that the vegetation cover, mostly bush thicket, became denser in 1979 than in 1973.

No or less than 5 % decrease in albedo were found, not surprisingly, in the main bed of Khor Abu Hahl. Another area showing very little change was a zone between the densely populated regions of Bara to the north and El Obeid and Umm Ruwaba to the south.



9.7



9.8



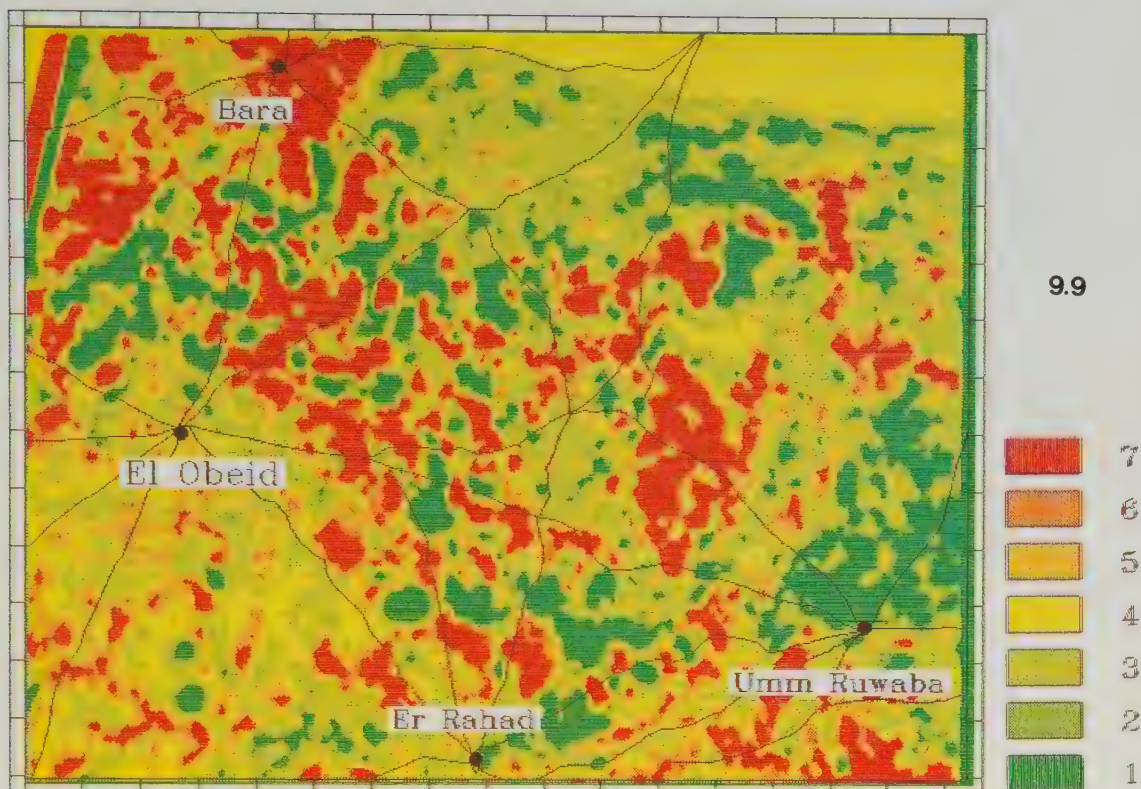


Fig. 9.9. Texture difference image, January 1973 - January 1979. Increased texture in e.g. the Umm Ruwaba area and the area to the east of Bara is due to a more prominent cultivation pattern, which is probably a sign of recovery of the vegetation. Increased texture in the NE part is due to abandoned fields. The colour scale corresponds to: 1 = increase more than 25 units, 2 = increase 25 - 20 units, 3 = increase 20 - 5 units, 4 = no change, 5 = decrease 5 - 10 units, 6 = decrease 10 - 15 units and 7 = decrease more than 15 units.

Fig. 9.7. Biomass difference image January 1979 - March 1979. From January to March we will expect the amount of green biomass to decrease. In this image we can see that the major decrease took place in the wadi areas (Khor Abu Habi), where the vegetation usually is green during much longer time of the year than in the Qoz areas. Also the eastern part of the Qoz area showed substantial decrease in biomass value. The colour scale corresponds to: 1 = no change, 2 = decrease less than 4 units, 3 = decrease 4 - 6 units and 4 = decrease more than 6 units.

Fig. 9.8. Biomass difference image March 1979 to September 1979. After the rainy season we can expect a general increase in biomass. In this image the Umm Ruwaba region shows the most significant increase. The colour scale corresponds to: 1 = increase 0 - 10 units, 2 = increase 10 - 20 units, 3 = increase 20 - 30 units, 4 = increase 30 - 40 units, 5 = increase 40 - 50 units and 6 = increase more than 50 units.

3.2 Changes from January 1979 to March 1979

Along with the dry season we can expect the albedo to increase and the biomass to decrease. An interesting question is then whether these changes are influenced by the population pressure or not. When comparing the conditions in January and March the same year, the climatic factors can be ignored and most changes be related to population and land-use factors.

In the albedo difference image, Fig. 9.5, we can see that most of the changes occurred in the Bara region, combining low rainfall with rather high population potential. The area with the highest population pressure, the area NE of Umm Ruwaba, showed however lower albedo increase.

The conclusion that can be drawn from this, is that the northern part of the study area was more subject to human over-exploitation than was the southern, more densely populated one.

3.3 Changes from March to September

After a rainy season, we can expect the biomass to increase and the albedo to decrease. These changes depend however mainly on the rainfall distribution during the rainy season. In Figs. 9.7 & 9.8, we can see that the most important changes took place in the Umm Ruwaba region. Another factor than the antecedent rainfall could be that the cultivated fields in the intensively cultivated region N and NE of Umm Ruwaba have very high biomass and low albedo.

All correlation coefficients are low. The only tendencies that can be seen are in the Umm Ruwaba area. Concerning the change in albedo from dry season to wet season (March - September), we can see that the largest albedo changes occur in areas with low population potential. This result was anticipated. Another result is that the largest increases in biomass from January 1973 to January 1979 occur in areas with a high population potential. This was also expected, since the most populated areas were the most degraded ones during the drought in 1973, and consequently the areas where the highest biomass increase could take place.

4. Relationships Between Biomass, Albedo and Rainfall

Apart from population pressure, rainfall is the main dynamic factor influencing albedo and biomass. In order to investigate the relationship between the average rainfall pattern, trend surfaces of the mean rainfall parameters (amount as well as number of days with at least 1 mm rainfall) were generated and geometrically registered and included in the raster data base. Since only a few rainfall stations were operational in the study area, it has been impossible to interpolate the antecedent rainfall data.

TAB IX:8 Correlation between rainfall parameters and changes in albedo and biomass between 1973 and 1979

ENTIRE QOZ:

	AMOUNT (mm)	NUMBER OF DAYS
ALBEDO JANUARY 1973:	-0.09	-0.10
ALBEDO JANUARY 1979:	-0.27 X	-0.20 x
ALBEDO MARCH 1979:	-0.40 X	-0.22 x
ALBEDO SEPTEMBER 1979:	-0.16	-0.06
BIOMASS JANUARY 1973:	-0.02	0.32 X
BIOMASS JANUARY 1979:	0.14	0.17
BIOMASS MARCH 1979:	0.12	0.30 X
BIOMASS SEPTEMBER 1979:	0.07	0.17
ALBEDO JAN 73 - JAN 79:	-0.10	-0.14
ALBEDO JAN 79 - MAR 79:	0.24 x	-0.20 x
ALBEDO MAR 79 - SEP 79:	-0.20 x	-0.13
BIOMASS JAN 73 - JAN 79:	-0.16	0.07
BIOMASS JAN 79 - MAR 79:	-0.08	-0.07
BIOMASS MAR 79 - SEP 79:	-0.06	-0.06

X = correlation coefficient over 0.3

x = correlation coefficient between 0.2 and 0.3

5. FINAL CONCLUSIONS

The aim of this thesis has been twofold, development of methodology for studies of land degradation, and the application of these methods on land degradation in a study area in Kordofan. Most of the effort has been put on the development of methodology. However, some interesting conclusions about desertification can be drawn.

The reports on desertification, previously presented in Chapter 2, have been very exaggerated and not based on a scientific approach. Most of the studies were based on comparison of two occasions, one prior to the Sahelian drought and another during or shortly after it. Not surprisingly, the environmental conditions degraded from the first to the second situation. In this study I have also compared two occasions only, but the first one during a period of drought and the second during more favourable climatic conditions. My conclusions have been the opposite in many cases. Signs of desertification can mainly be seen during extremely dry periods, like the Sahelian drought and the present dry period. When the rainfall returns to normal both the natural vegetation and agricultural crops recover.

It has not been possible to find a consistent trend of a degrading landscape. The conditions vary with the climatic conditions. An area with appropriate land-use in a year with adequate rainfall may suffer from crop failure and show signs of over-exploitation another year.

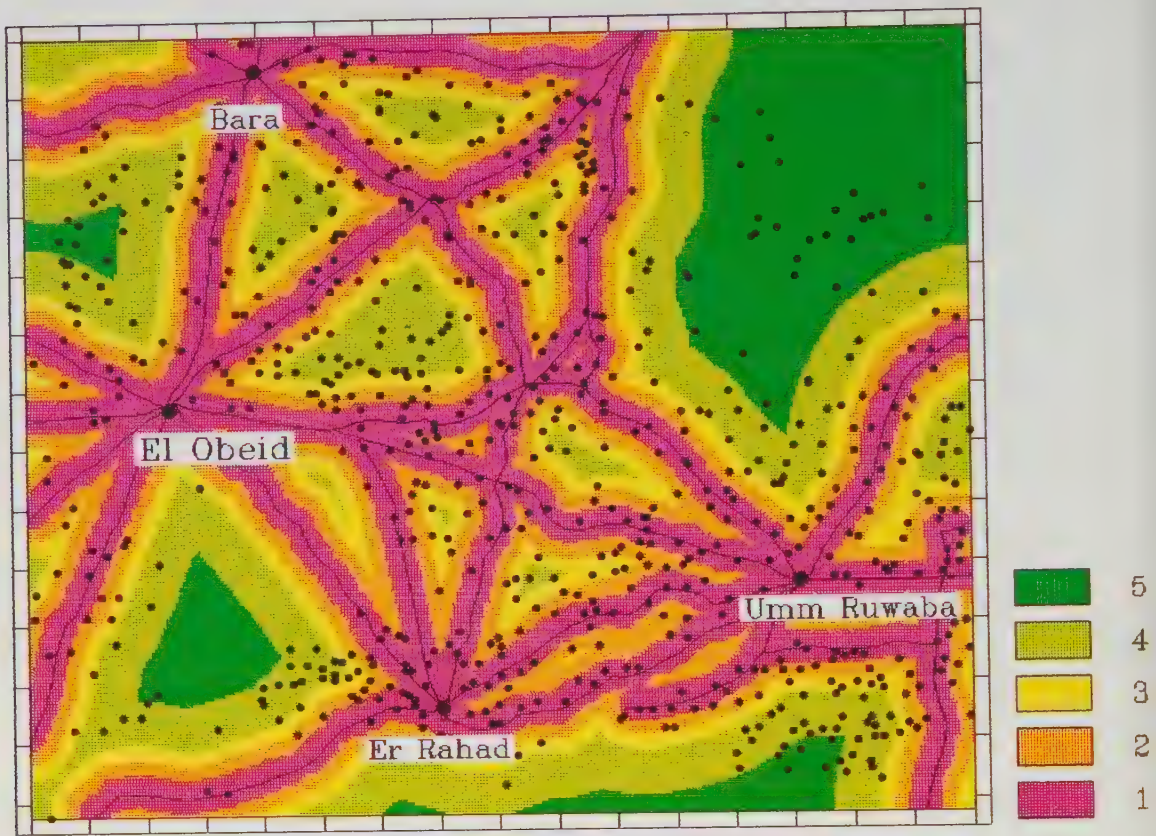


Fig. 6.19. Map showing the distance to nearest main road. The colour scale corresponds to: 1 = 0 - 2.5 km, 2 = 2.5 - 5 km, 3 = 5 - 7.5 km, 4 = 7.5 - 15 km and 5 = over 15 km.

Scale: Interval between tickmarks corresponds to 10 km.

Appendix

ANALYSIS OF VARIANCE BETWEEN SAMPLED FIELD DATA AND LANDSAT DATA

The geographical coordinates of the field data points were used to extract a window of 11 by 11 pixels around each point. The mean values of the windows were used in one-way analysis of variance between individual MSS bands and different image transformations.

The field data points were collected during field work in February and March 1982. The environmental variables estimated at each point are described in Chapter three.

The Landsat MSS images used were from January 06 1979, March 19 1979 and September 24 1979. The scenes correspond to the world reference system (Landsat 1 - 3) coordinate: Path 187, Row 51.

The images were firstly resampled to each other (50 m pixels) and secondly resampled to the UTM grid net, corresponding with the topographical maps NC 36 M and NC 36 I, in the scale of 1 to 250 000. The pixel size was transformed to 250 m.

1. VEGETATION TYPE:

1. No natural vegetation	n = 38
2. grassland	n = 9
3. bush grassland	n = 247
4. tree grassland	n = 111
5. bush tree grassland	n = 13
6. bushland	n = 33
7. woodland and bush woodland	n = 23

The degrees of freedom were, numerator: 6, denominator: 467

A. March MSS 4:
F-ratio = 0.86

MEAN	STDEV	
34 53	4 46	=====
34 22	2 39	(-----)
34 72	3 48	(-----)
34 04	3 04	(-----)
35 15	2 58	(-----)
35 27	3 19	(-----)
34 48	3 30	(-----)

B. March MSS 5:
F-ratio = 1.45

MEAN	STDEV	
60 92	13 83	=====
61 33	4 74	(-----)
62 02	10 81	(-----)
60 35	8 82	(-----)
65 31	6 52	(-----)
65 61	9 36	(-----)
60 87	10 35	(-----)

C. March MSS 7:
F-ratio = 1.48

MEAN	STDEV	
57 68	13 70	=====
57 89	6 03	(-----)
58 51	11 05	(-----)
56 96	8 74	(-----)
62 69	5 89	(-----)
62 21	10 22	(-----)
57 96	9 30	(-----)

D. September MSS 4:
F-ratio = 2.43

MEAN	STDEV	
32 45	5 78	=====
31 78	1 99	(-----)
33 03	4 79	(-----)
31 53	4 04	(-----)
33 31	3 04	(-----)
34 45	4 18	(-----)
31 78	5 54	(-----)

E. September MSS 5:
F-ratio = 2.19

MEAN	STDEV	
51 39	17 09	=====
51 44	3 91	(-----)
53 58	13 82	(-----)
50 50	12 18	(-----)
56 62	7 77	(-----)
59 09	11 58	(-----)
51 13	15 15	(-----)

F. September MSS 7:
F-ratio = 2.27

MEAN	STDEV	
54 89	11 79	=====
55 89	5 44	(-----)
56 05	10 69	(-----)
53 89	8 79	(-----)
59 69	5 94	(-----)
60 36	9 65	(-----)
54 35	9 53	(-----)

G. September PC 1:
F-ratio = 5.79

MEAN	STDEV	
110 18	45 52	=====
123 44	14 23	(-----)
115 34	38 95	(-----)
125 90	35 45	(-----)
85 69	20 86	(-----)
90 48	33 61	(-----)
128 09	39 35	(-----)

H. September PC 2:
F-ratio = 5.42

MEAN	STDEV	
120 7	28 7	=====
132 7	29 7	(-----)
115 1	35 3	(-----)
129 7	26 8	(-----)
141 1	20 5	(-----)
132 4	28 9	(-----)
105 3	29 5	(-----)

I. March PC 1:
F-ratio = 4.58

MEAN	STDEV	
110 13	49 10	[=====] [=====] [=====]
129 33	18 85	(-----)
122 20	38 86	(-----)
129 41	36 43	(-----)
90 92	23 63	(-----)
98 58	40 90	(-----)
121 52	40 76	(-----)

J. March PC 2:
F-ratio = 4.02

MEAN	STDEV	
125 3	14 5	[=====] [=====] [=====]
130 9	15 7	(-----)
128 4	18 2	(-----)
127 9	14 5	(-----)
136 8	10 9	(-----)
135 9	16 5	(-----)
116 3	11 1	(-----)

K. January Albedo:
F-ratio = 3.21

MEAN	STDEV	
17 95	4 24	[=====] [=====] [=====]
20 22	1 86	(-----)
19 01	3 68	(-----)
19 64	3 34	(-----)
16 85	2 19	(-----)
17 30	3 96	(-----)
18 83	3 93	(-----)

L. March Albedo:
F-ratio = 2.81

MEAN	STDEV	
23 00	5 88	[=====] [=====] [=====]
25 33	2 45	(-----)
24 15	5 25	(-----)
24 93	4 79	(-----)
20 85	2 85	(-----)
21 88	4 81	(-----)
24 22	4 82	(-----)

M. September Albedo:
F-ratio = 5.61

MEAN	STDEV	
18 18	5 79	[=====] [=====] [=====]
19 89	1 96	(-----)
18 79	4 94	(-----)
20 18	4 50	(-----)
15 15	2 67	(-----)
15 73	4 38	(-----)
20 39	5 13	(-----)

N. September TND:
F-ratio = 2.95

MEAN	STDEV	
114 5	12 1	[=====] [=====] [=====]
108 4	6 3	(-----)
110 3	17 7	(-----)
105 9	13 3	(-----)
112 8	11 0	(-----)
115 1	10 2	(-----)
115 0	13 6	(-----)

O. March TND:
F-ratio = 1.49

MEAN	STDEV	
93 16	3 02	[=====] [=====] [=====]
92 00	1 87	(-----)
90 15	10 77	(-----)
89 90	9 18	(-----)
90 85	4 38	(-----)
92 24	2 40	(-----)
94 13	3 03	(-----)

2. CANOPY COVER:

- | | |
|--------------------------|---------|
| 1. No canopy cover | n = 119 |
| 2. | n = 144 |
| 3. | n = 80 |
| 4. | n = 95 |
| 5. | n = 24 |
| 6. complete canopy cover | n = 12 |

The degrees of freedom were, numerator: 5, denominator: 468

A. March MSS 4:
F-ratio = 5.92

MEAN	STDEV	
34 19	3 75	[=====] [=====] [=====]
34 43	3 40	(-----)
35 30	3 62	(-----)
33 81	2 65	(-----)
36 25	2 44	(-----)
38 00	0 74	(-----)

B. March MSS 5:
F-ratio = 4.90

MEAN	STDEV	
60 34	11 35	[=====] [=====] [=====]
61 09	10 14	(-----)
63 95	11 13	(-----)
60 47	8 67	(-----)
65 92	8 49	(-----)
71 17	4 22	(-----)

C. March MSS 7:
F-ratio = 4.48

MEAN	STDEV	===== ===== ===== =====
56 92	11 06	(---●---)
57 31	10 49	(---●---)
60 41	11 95	(---●---)
57 86	8 54	(---●---)
63 37	7 75	(---●---)
67 58	4 42	(---●---)
		===== ===== ===== =====
		60 0 65 0 70 0

D. September MSS 4:
F-ratio = 8.22

MEAN	STDEV	===== ===== ===== =====
31 84	4 90	(---●---)
32 95	4 55	(---●---)
33 87	4 64	(---●---)
31 03	3 86	(---●---)
35 08	4 66	(---●---)
37 08	3 65	(---●---)
		===== ===== ===== =====
		33 0 36 0 39 0

E. September MSS 5:
F-ratio = 5.38

MEAN	STDEV	===== ===== ===== =====
50 30	14 10	(---●---)
53 33	13 18	(---●---)
55 95	13 55	(---●---)
50 29	12 12	(---●---)
59 87	13 25	(---●---)
63 42	10 87	(---●---)
		===== ===== ===== =====
		52 5 60 0 67 5

F. September MSS 7:
F-ratio = 2.79

MEAN	STDEV	===== ===== ===== =====
54 19	10 09	(---●---)
54 99	10 65	(---●---)
57 42	11 26	(---●---)
55 75	8 91	(---●---)
59 75	7 22	(---●---)
61 75	6 41	(---●---)
		===== ===== ===== =====
		55 0 60 0 65 0 70 0

G. September PC 1:
F-ratio = 5.68

MEAN	STDEV	===== ===== ===== =====
112 13	42 69	(---●---)
118 93	33 51	(---●---)
116 45	40 59	(---●---)
124 66	34 71	(---●---)
94 83	41 27	(---●---)
75 17	37 55	(---●---)
		===== ===== ===== =====
		72 96 120

H. September PC 2:
F-ratio = 6.87

MEAN	STDEV	===== ===== ===== =====
126 70	34 67	(---●---)
116 71	33 84	(---●---)
113 01	29 50	(---●---)
130 31	26 07	(---●---)
120 42	30 40	(---●---)
85 83	33 99	(---●---)
		===== ===== ===== =====
		80 100 120

I. March PC 1:
F-ratio = 9.16

MEAN	STDEV	===== ===== ===== =====
115 94	45 15	(---●---)
127 06	34 03	(---●---)
120 68	40 20	(---●---)
129 62	31 29	(---●---)
93 62	40 87	(---●---)
68 25	39 01	(---●---)
		===== ===== ===== =====
		60 90 120 150

J. March PC 2:
F-ratio = 3.61

MEAN	STDEV	===== ===== ===== =====
130 1	19 4	(---●---)
129 2	17 0	(---●---)
125 6	14 0	(---●---)
129 6	15 0	(---●---)
125 2	12 8	(---●---)
111 2	14 9	(---●---)
		===== ===== ===== =====
		110 120 130

K. January Albedo:
F-ratio = 9.08

MEAN	STDEV	===== ===== ===== =====
18 47	4 18	(---●---)
19 51	3 37	(---●---)
18 86	3 63	(---●---)
19 77	2 55	(---●---)
16 67	3 58	(---●---)
13 92	4 17	(---●---)
		===== ===== ===== =====
		12 0 14 4 16 8 19 2

L. March Albedo:
F-ratio = 7.03

MEAN	STDEV	===== ===== ===== =====
23 45	6 25	(---●---)
24 62	4 61	(---●---)
24 10	4 85	(---●---)
25 21	3 73	(---●---)
21 17	4 71	(---●---)
17 92	4 56	(---●---)
		===== ===== ===== =====
		16 0 19 2 22 4 25 6

M. September Albedo:
F-ratio = 5.81

MEAN	STDEV	===== ===== ===== =====
18 49	5 41	(---●---)
19 24	4 23	(---●---)
18 89	5 18	(---●---)
20 03	4 41	(---●---)
16 17	5 40	(---●---)
13 58	4 78	(---●---)
		===== ===== ===== =====
		12 0 15 0 18 0 21 0

N. September TND:
F-ratio = 7.53

MEAN	STDEV	===== ===== ===== =====
107 2	20 1	(---●---)
109 0	15 8	(---●---)
113 5	11 4	(---●---)
108 5	9 2	(---●---)
117 0	9 9	(---●---)
130 7	15 8	(---●---)
		===== ===== ===== =====
		110 120 130 140

0. March TND:
F-ratio = 3.22

MEAN	STDEV	====[=====][=====][=====]====
88 82	12 70	(---*---)
90 07	9 95	(---*---)
92 37	5 80	(---*---)
91 31	4 76	(---*---)
93 46	1 98	(---*---)
96 42	3 75	(---*---)
		====[=====][=====][=====]====
		88 0 92 0 96 0 100 0

3. FIELD COVER:

1. No field cover	n = 114
2.	n = 217
3.	n = 69
4.	n = 34
5.	n = 19
6.	n = 11
7. complete field cover	n = 10

The degrees of freedom were: numerator: 6, denominator: 467

A. March MSS 4:
F-ratio = 9.54

MEAN	STDEV	====[=====][=====][=====]====
34 98	3 18	(---*---)
35 10	2 99	(---*---)
34 48	3 37	(---*---)
34 18	4 25	(---*---)
30 79	3 19	(---*---)
32 27	3 07	(---*---)
30 30	4 14	(---*---)
		====[=====][=====][=====]====
		30 0 32 0 34 0

B. March MSS 5:
F-ratio = 6.28

MEAN	STDEV	====[=====][=====][=====]====
63 59	9 81	(---*---)
62 44	9 01	(---*---)
62 45	11 11	(---*---)
59 74	13 82	(---*---)
52 58	10 85	(---*---)
60 64	10 39	(---*---)
49 30	10 53	(---*---)
		====[=====][=====][=====]====
		45 0 52 5 60 0 67 5

C. March MSS 7:
F-ratio = 7.39

MEAN	STDEV	====[=====][=====][=====]====
60 28	9 75	(---*---)
59 13	9 02	(---*---)
59 35	10 63	(---*---)
56 18	13 61	(---*---)
47 68	13 40	(---*---)
55 91	11 63	(---*---)
46 00	10 88	(---*---)
		====[=====][=====][=====]====
		45 0 52 5 60 0

D. September MSS 4:
F-ratio = 2.52

MEAN	STDEV	====[=====][=====][=====]====
33 45	4 74	(---*---)
32 81	4 31	(---*---)
32 41	5 22	(---*---)
31 76	5 93	(---*---)
31 00	3 23	(---*---)
32 36	2 69	(---*---)
28 60	4 86	(---*---)
		====[=====][=====][=====]====
		27 0 30 0 33 0 36 0

E. September MSS 5:
F-ratio = 3.44

MEAN	STDEV	====[=====][=====][=====]====
55 71	13 34	(---*---)
53 19	12 27	(---*---)
52 97	15 31	(---*---)
49 76	17 69	(---*---)
46 84	9 78	(---*---)
53 64	9 65	(---*---)
39 80	12 98	(---*---)
		====[=====][=====][=====]====
		40 50 60

F. September MSS 7:
F-ratio = 7.39

MEAN	STDEV	====[=====][=====][=====]====
57 62	9 46	(---*---)
56 38	8 80	(---*---)
57 04	10 08	(---*---)
53 03	12 88	(---*---)
44 84	12 76	(---*---)
53 00	11 38	(---*---)
45 60	10 98	(---*---)
		====[=====][=====][=====]====
		42 0 48 0 54 0 60 0

G. September PC 1:
F-ratio = 1.85

MEAN	STDEV
118 56	42 81
114 69	38 69
116 52	40 80
97 85	36 59
128 16	15 31
121 27	20 25
126 80	14 34

H. September PC 2:
F-ratio = 1.28

MEAN	STDEV
115 1	36 8
122 7	32 9
118 3	32 5
126 4	30 6
120 8	15 9
134 5	16 1
125 1	16 3

I. March PC 1:
F-ratio = 2.23

MEAN	STDEV
122 9	42 2
118 9	39 2
120 7	42 6
104 1	42 0
136 2	16 8
129 1	24 8
143 0	14 2

J. March PC 2:
F-ratio = 0.78

MEAN	STDEV
126 2	17 8
129 9	17 2
127 7	15 7
127 9	19 2
126 8	10 8
128 5	11 4
123 7	3 3

K. January Albedo:
F-ratio = 2.48

MEAN	STDEV
19 00	3 84
18 83	3 59
18 83	3 88
17 35	4 26
20 58	1 71
19 91	2 39
21 10	1 45

L. March Albedo:
F-ratio = 2.26

MEAN	STDEV
24 19	5 30
23 74	5 01
24 42	5 78
21 94	5 52
26 05	2 04
25 45	2 94
26 70	2 26

M. September Albedo:
F-ratio = 1.87

MEAN	STDEV
19 18	5 45
18 76	4 91
18 93	5 19
16 59	4 70
20 53	2 04
19 73	2 49
20 30	1 83

N. September TND:
F-ratio = 0.50

MEAN	STDEV
112 1	17 2
109 2	15 5
110 8	16 1
109 8	18 0
110 3	4 1
109 0	4 8
107 3	6 3

O. March TND:
F-ratio = 0.48

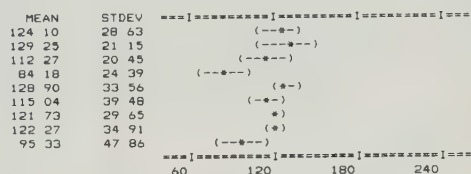
MEAN	STDEV
91 36	8 62
90 17	9 61
91 00	9 22
89 82	12 13
92 53	1 35
92 45	1 75
91 30	5 42

4. SOIL COLOUR:

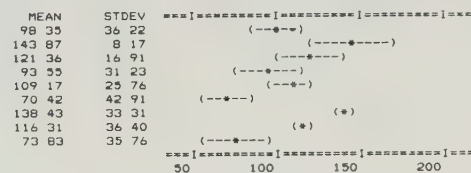
1.	713	n =	20
2.	715	n =	4
3.	751	n =	8
4.	753	n =	6
5.	791	n =	12
6.	1511	n =	11
7.	1513	n =	29
8.	1515	n =	26
9.	1551	n =	219
10.	1553	n =	118
11.	1555	n =	3
12.	1591	n =	2
13.	2315	n =	4
14.	2355	n =	12

The degrees of freedom were: numerator: 13, denominator: 460.

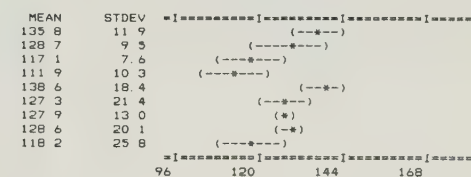
A. March MSS 4:
F-ratio = 10.67



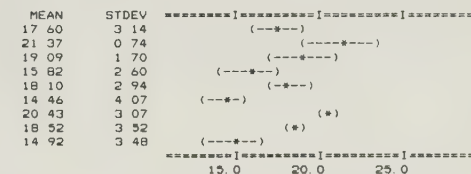
B. March MSS 5:
F-ratio = 7.47



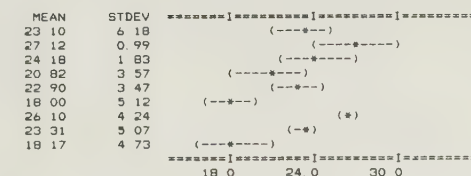
C. March MSS 7:
F-ratio = 7.41



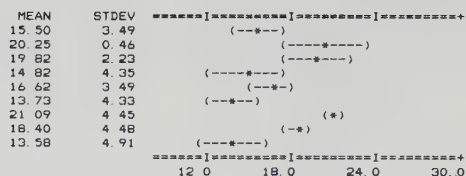
D. September MSS 4:
F-ratio = 4.44



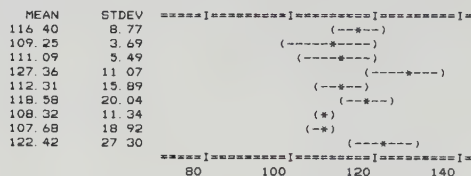
E. September MSS 5:
F-ratio = 3.68



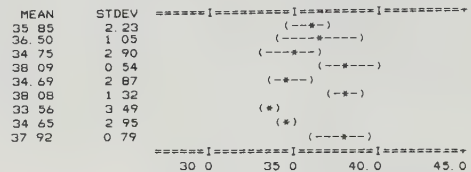
F. September MSS 7:
F-ratio = 4.74



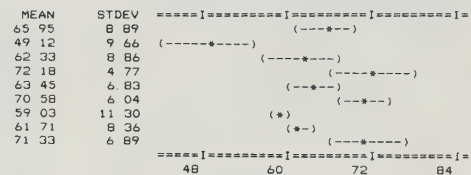
G. September PC 1:
F-ratio = 13.09



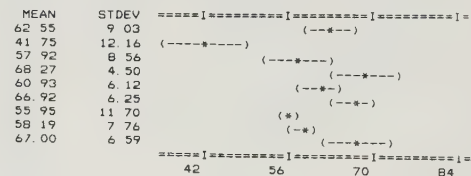
H. September PC 2:
F-ratio = 2.44



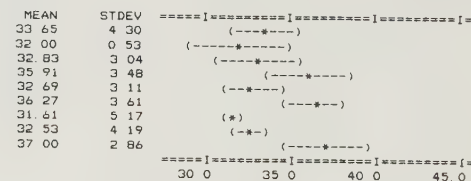
I. March PC 1:
F-ratio = 14.48



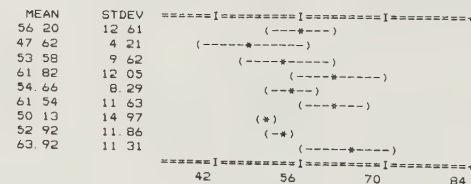
J. March PC 2:
F-ratio = 2.99



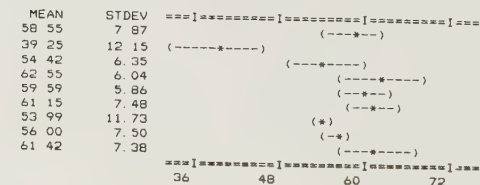
K. January Albedo:
F-ratio = 11.52



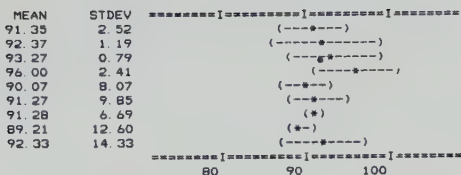
L. March Albedo:
F-ratio = 10.70



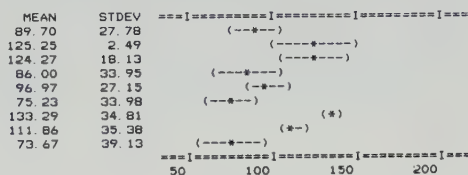
M. September Albedo:
F-ratio = 12.16



N. September TND:
F-ratio = 3.74



O. March TND:
F-ratio = 1.54

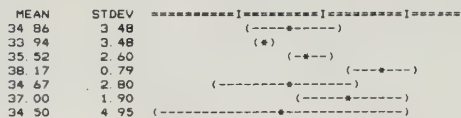


5. SOIL TYPE:

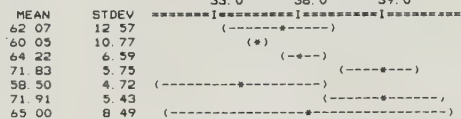
- | | |
|-----------------------|---------|
| 1. No natural ground | n = 14 |
| 2. Sand | n = 334 |
| 3. Silt | n = 77 |
| 4. Clay | n = 30 |
| 5. Gravel and coarser | n = 6 |
| 6. Pediment | n = 11 |

The degrees of freedom were, numerator: 6, denominator: 467

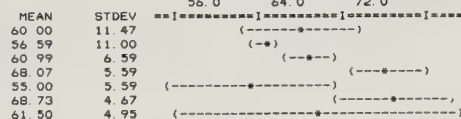
A. March MSS 4:
F-ratio = 10.56



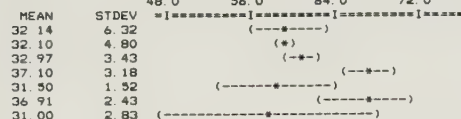
B. March MSS 5:
F-ratio = 9.77



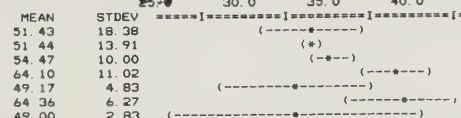
C. March MSS 7:
F-ratio = 9.53



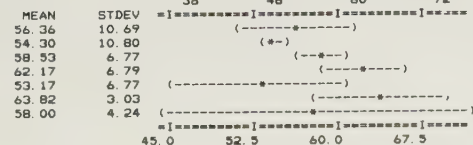
D. September MSS 4:
F-ratio = 7.58



E. September MSS 5:
F-ratio = 6.05



F. September MSS 7:
F-ratio = 5.66



G. September PC 1:
F-ratio = 27.66

MEAN	STDEV	=====
128.43	50.97	(-----)
126.24	35.18	(*)
95.19	25.33	(---)
60.67	31.19	(---)
116.17	10.98	(-----)
68.36	19.26	(-----)
123.50	6.36	(-----)

H. September PC 2:
F-ratio = 2.75

MEAN	STDEV	=====
118.8	32.9	(-----)
119.1	30.4	(*)
129.1	34.9	(---)
109.8	46.7	(---)
134.5	12.6	(-----)
126.9	21.5	(-----)
118.0	76.4	(-----)

I. March PC 1:
F-ratio = 30.69

MEAN	STDEV	=====
128.86	48.95	(-----)
130.99	35.35	(*)
105.61	25.92	(---)
55.20	32.97	(---)
126.33	14.79	(-----)
69.73	23.21	(-----)
129.50	7.78	(-----)

J. March PC 2:
F-ratio = 5.81

MEAN	STDEV	=====
122.4	13.8	(-----)
126.7	15.3	(*)
135.6	18.0	(---)
122.9	25.0	(---)
148.2	5.2	(-----)
135.5	4.2	(-----)
130.0	24.0	(-----)

K. January Albedo:
F-ratio = 24.26

MEAN	STDEV	=====
19.07	4.41	(-----)
19.75	3.35	(*)
17.90	2.59	(---)
13.03	3.30	(---)
20.33	1.03	(-----)
15.18	2.27	(-----)
19.50	0.71	(-----)

L. March Albedo:
F-ratio = 20.66

MEAN	STDEV	=====
23.14	5.83	(-----)
25.13	4.72	(*)
22.40	3.33	(---)
16.13	4.12	(---)
25.00	1.67	(-----)
20.91	7.79	(-----)
25.00	0.00	(-----)

M. September Albedo:
F-ratio = 27.60

MEAN	STDEV	=====
20.50	6.48	(-----)
20.20	4.46	(*)
16.26	3.33	(---)
11.87	3.94	(---)
19.00	1.41	(-----)
12.82	2.44	(-----)
19.50	0.71	(-----)

N. September TND:
F-ratio = 5.90

MEAN	STDEV	=====
112.9	12.9	(-----)
108.2	14.6	(*)
112.1	15.0	(---)
123.2	23.9	(---)
105.2	2.2	(-----)
120.5	8.2	(-----)
110.5	13.4	(-----)

O. March TND:
F-ratio = 0.39

MEAN	STDEV	=====
93.21	3.29	(-----)
90.55	9.62	(*)
90.29	7.08	(---)
92.23	12.40	(---)
90.17	0.41	(-----)
91.82	3.09	(-----)
92.00	2.83	(-----)

References

- Agterberg F., 1984: Trend Surface Analysis. pp 147 - 172 in Gaile & Willmott 1984.
- Ahlcrona E., 1984: Report from a Journey to White Nile Province and Northern Kordofan Province, 25th of October - 2nd of November 1984. (mimeo) unpublished, 5 p.
- Alvey N.G, Banfield C.F., Gower J.C., Krzanowski W.J., Lane P.W., Leech P.K., Nelder J.A., Payne R.W., Phelps K.M., Rogers C.E., Ross G.J.S., Simpson H.R., Todd A.D., Wedderburn R.W.M. & Wilkinson G.N., 1977: GENSTAT A General Statistical Program. Rothamsted Experimental Station.
- Asad T., 1970: The Khababish Arabs. Hurst & Co. London, 263 p.
- Bauer M.E., Cipra J.E., Anuta P.E. & Etheridge J.B. 1979: Identification and Area Estimation of Agricultural Crops by Computer Classification of Landsat MSS Data. Remote Sensing of Environment Vol 8. pp 77 92.
- Bayoumi A.A., 1984: Renewable Natural Resource Management and Desertification in the Sudan. At Tasahhur (Sudan Journal of Desertification) Volume 2, pp 1 - 11.
- Born M., 1965: Zentralkordofan, Bauern un Nomaden in Savannengebieten des Sudan. Marburger Geographisches Schriften, Heft 25, 260 p. Marburg
- Breman H. & de Wit C.T. 1983: Rangeland Productivity and Exploitation in the Sahel. Science Vol. 221 No: 4618, pp. 1341 - 1347.
- Brink A.B., Mabbutt, J.A., Webster R. & Beckett P.H.T, 1966: Report of the working group on land classification and data storage. MEXE Report No. 940.
- Bryson R.A., 1974: personal communication qouted in Otterman & Fraser 1976
- Bunge W., 1962: Theoretical Geography, Lund Studies in Geography Ser C, Vol 1.
- Byrne G.R. & Crapper P.F., 1979: An Example of the Detection of Changes Between Successive Landsat Images by Numerical Methods in an Urban Area. Proc. LANDSAT 79, 1st Australasian Conf. on Remote Sensing.
- Byrne G.R., Crapper P.F. & Mayo K.K., 1980: Monitoring Land Cover Changes by Principal Components Analysis of Multitemporal Landsat Data. Remote Sensing of Environment Vol 10, pp 175 - 184.

- Carey H.C., 1858-65: Principles of Social Sciences, Vol 1 - 3. Philadelphia: Lippincott.
- Clarke J.I., 1965: Population Geography, Pergamon Press, 164 p.
- Cliffe L., (no date): Capitalism or Feudalism? the Famine in Ethiopia.
- Cochran W.G. 1977: Sampling Techniques. John Wiley & sons. 428 p.
- Coiner J.C., 1980: Using Landsat to Monitor Changes in Vegetation Cover Induced by Desertification Processes. Proc. 14th International Symposium on Remote Sensing of Environment, Costa Rica, pp 1341 - 1351
- Dahl G. & Hjort A., 1976: Having Herds: Pastoral Herd Growth and Household Economy. Stockholm Studies in Social Anthropology.
- Dancette C. & Hall A.E., 1979: Agroclimatology Applied to Water Management in the Sudano Sahelian Zone of Africa. Chapter 4 in Hall et.al. 1979.
- Darrag A., 1984: Drought, Desertification and Desert Encroachment in Kordofan and Darfur Regions. Report on the findings of the FAO/WFP and Sudan Government officials fact finding mission 26 - 29 January 1984. (mimeo) 19 p
- Daultrey S., 1976: Principal Components Analysis. Concepts and Techniques in Modern Geography No: 8. Geo Abstract, Norwich, England 50 p.
- DECARP 1976: Sudan Desert Encroachment Control and Rehabilitation Program. Prepared jointly by the General Administration for Natural Resources, Ministry of Agriculture, Food and Natural Resources, The Agriculture Research Council, National Council for Research in collaboration with UNEP and FAO, Khartoum, Sudan, 277 p.
- Dent D. & Young A., 1981: Soil Survey and Land Evaluation. George Allen & Unwin, London, 278 p.
- Department of Statistics, 1980: Second Population Census 1973, Vol II, Population Dynamics, Ministry of National Planning, Khartoum, Sudan.
- Dregne H.E., 1976: Desertification: Symptom of a Crisis. Quoted in Reining 1978.
- Eckholm E. & Brown L.R., 1977: Spreading Deserts - The Hand of Man. Worldwatch Paper No. 13, Washington D.C., 40 p.
- Estes J.E., Jensen J.J. & Simonett D.S., 1980: Impacts of Remote Sensing on US Geography. Remote Sensing of Environment Vol 10, No 1, pp 43 - 80.

European Software Contractors, 1984: UNIRAS GEOPAK, GIMAGE, Interpolation and RASPAK, Users Manuals, Lyngby, Copenhagen, Denmark.

Flowerdew R., 1985: Chinese Settlement Pattern Analysis Using SIR-A Data: A Comment. International Journal of Remote Sensing, Vol 6, No 2 pp 381-382.

Freeman H., 1980: Analysis and Manipulation of Lineal Map Data. Chapter 8, pp 151 - 168, in Freeman & Pieroni 1980.

Freeman H. & Pieroni G.G., (eds) 1980: Map Data Processing, Academic Press, New York, 374 p.

Freiburger W.F., (ed) 1960: The International Dictionary of Applied Mathematics. Van Nostrand, Princeton, N.J. 412 p.

Gaile G.L. & Willmott C.J. 1984: Spatial Statistics and Models. D. Reidel Publishing Company. 480 p.

van Genderen J.L., Lock B.F. & Vass P.A., 1978: Remote Sensing: Statistical Testing of Thematic Map Accuracy. Remote Sensing of Environment, Vol 7, No. 1, pp. 3-14

Glantz M.H., 1977 (ed): Desertification - Environmental Degradation in and around Arid Lands. Westview Press, Boulder, Col. U.S.A. 346 p

Glover J. & Robinson P., 1953: A Simple Method for Assessing the Reliability of Rainfall. Journal of Agricultural Science, Vol. 43, pp 275-280.

Graetz R.D., Gentle M.R., Pech R.P. & O'Callaghan J.F. 1982: The Development of a Land Image-Based Resource Information System (LIBRIS) and its Application to the Assessment and Monitoring of Australian Arid Rangelands. Proc. Int. Symp. on Remote Sensing of Arid and Semi Arid Lands, Cairo. Vol 1, pp 257 - 273.

Graetz R.D., Pech R.P., Hindley N.L. & Gentle M.R., 1984: The Application of Landsat to Rangeland Management: LIBRIS Five Years On. Proc. LANDSAT 84 - Third Australasian Remote Sensing Conference, pp 322 - 331.

Grainger 1982: Desertification, Earthscan Paperback, London, 94 p.

Greig-Smith P., 1983: Quantitative Plant Ecology, Studies in Ecology Vol. 9, Blackwell Scientific Publications, Oxford.

Gregory S., 1969: Rainfall Reliability, in Thomas & Whittington 1969: Environment and Land Use in Africa, pp 62 - 83.

Griffith D.A. 1984: Theory of Spatial Statistics, in Gaile and Willmott 1984.

Hall A.E., Cannel G.H. & Lawton H.W. 1979: Agriculture in Semi

Arid Environments. Springer Verlag, New York, 340 p.

Hall K & Olsson L., 1984: Empirical Studies of the Relationship Between Landsat MSS-data and Topography, Proc. 18th International Symposium on Remote Sensing of Environment, Paris, France, pp. 1835 - 1844

Hammer-Digernes T., 1977: Wood for Fuel - Energy Crisis Implying Desertification. Geografisk Institutt, Universitetet i Bergen, 124 p.

Hanuschak G.A. & Morrissey K.M., 1977: Pilot Study of the Potential Contributions of Landsat Data in the Construction of Area Sampling Frames. Statistical Reporting Service, USDA, Washington D.C., 66 p.

Haralick, R. M. & Shanmagan, K. S., 1974: Combined Spectral and Spatial Processing of ERTS Imagery Data. Remote Sensing of Environment, Vol 3, pp 3 - 13.

Hay A.M., 1979: Sampling Designs to Test Land-Use Map Accuracy. Photog. Eng. & Remote Sensing, Vol. 45, No. 4, pp. 529-533.

Hellden U., 1978: Evaluation of Landsat-2 Imagery for Desertification Studies in Northern Kordofan, Sudan. Lund University, Dept. of Physical Geography, R.o.N. No. 38, 37 p.

Hellden U., 1979: A Test of Landsat-1 Imagery and Digital Data for Vegetation and Land Use Mapping in Scania. Lund University Dept. of Physical Geography, R.o.N. No: 44.

Hellden U., 1980: A Test of Landsat-2 Imagery and Digital Data for Thematic Mapping, Illustrated by an Environmental Study in Northern Kenya. Lund University, Dept. of Physical Geography, R.o.N. No:47

Hellden U., 1981(a): Landsat Data as an Aid for Obtaining Agricultural Statistics - Illustration of an Area Sampling Frame Construction in Niger. Final Report, FAO, TCP project NER/8904. 22 p.

Hellden U., 1981(b): Satellite Data for Regional Studies of Desertification and its Control. Lund University Dept. of Physical Geography, R.o.N. No: 50.

Hellden U., 1984: Drought Impact Monitoring - A Remote Sensing Study of Desertification in Kordofan, the Sudan. Lund University, Dept. of Physical Geography R.o.N. No: 61, 55 p.

Hellden U., 1985: Remote Sensing for Regional Studies of Desertification - NOAA Data for Crop Yield and Drought Impact Studies in the Sudan. Lund University, Dept. of Geography, R.o.N. No. 66

Hellden U. & Olsson K., 1982: The Potential of Landsat MSS Data for Wood Resources Monitoring. - A Study in Arid and Semi Arid Environment in Kordofan, The Sudan. Lund University Dept. of

Physical Geography, R.o.N. No: 52.

Hellden U., Olsson L. & Stern M., 1982: Approaches to Desertification Monitoring in the Sudan. Proc. of an EARSeL-ESA Symposium, Igls, Austria, pp 131-144.

Hellden U. & Stern M., 1980: Monitoring Land Degradation in Southern Tunisia - A Test of Landsat Imagery and Digital Data. Lund University Dept. of Physical Geography, R.o.N. No: 48

Hoffer R.M., 1978: Biological and Physical Considerations in Applying Computer-Aided Analysis Techniques to Remote Sensor Data. Chapter 5 in Swain & Davis 1978.

Hord R.M. & Brooner W., 1976: Land-Use Map Accuracy Criteria. Photogr. Eng. & Remote Sensing, Vol. 42, No. 5, pp. 671-677.

Horowitz M. M., 1981: Social Analysis of Desertification and its Control in Kordofan and Darfur Provinces, Democratic Republic of the Sudan. Draft submitted to UNSO.

Houseman E.E., 1975: Area Frame Sampling in Agriculture. Statistical reporting Service, USDA SRS No. 20. 79 p.

Hsu S., 1978: Texture-Tone Analysis for Automated Land-Use Mapping. Photogr. Eng. and Remote Sensing, Vol. 44, pp 1393 - 1404.

Hsu S. & Burright R.G., 1980: Texture Perception and the RADC/Hsu Texture Feature Extractor. Photogr. Eng. and Remote Sensing, Vol 46, pp 1051 - 1058.

Hugli H. & Frei W., 1983: Understanding Anisotropic Reflectance in Mountainous Terrain. Phot. Eng. & Rem. Sens. Vol 49, No 5, pp 671 683.

Ibrahim F., 1978: Anthropogenic Causes of Desertification in Western Sudan. Geo Journal Vol. 23, pp 243-254.

Ibrahim F., 1980: Desertification in Nord Darfur. Hamburger Geographische Studien, Heft 35, 170 p.

Ibrahim F., 1984: The Problem of Overstocking and Ecological Degradation in the Republic of the Sudan. At Tasahhur (Sudan Journal of Desertification) Vol. 2.pp 12-20.

Irons, J. R. & Petersen G. W., 1981: Texture Transforms of Remote Sensing Data. Remote Sensing of Environment Vol 11, pp 359 - 370.

Jackson R.D., 1983: Spectral Indices in n-Space. Remote Sensing of Environment Vol. 13, pp. 409-421.

Jones M.J., 1973: the Organic Matter Content of the Savanna Soils of West Africa. Soil Science Vol. 24, pp. 42-53.

Kauth R.J. & Thomas G.S., 1976: The Tasseled Cap - A Graphic

Description of the Spectral-Temporal Development of Agricultural Crops as seen by Landsat. Proc. Symposium of Machine Processing of Remote Sensing Data. LARS, Purdue, IEEE Cat. No. 76, Ch. 1103-1 MPRSD.

Katz R.W. & Glantz M.H., 1977: Rainfall Statistics, Droughts and Desertification in the Sahel. Chapter 5 in Glantz 1977.

Khogali M., 1980 & 1983: Personal communications

King L., J., 1969: Statistical Analysis in Geography. Prentice - Hall.

King L., J. 1984: Central Place Theory. Sage Publications, Beverly Hills.

Kondratyev K.Ya., Dyachenko L.N & Piatovskaya N.P., 1974: On the Relationship Between the Earth-Atmosphere System Albedo and the Earth's Surface Albedo. in Earth Survey Problems, Akademie Verlag, Berlin, pp 473 - 482. (quoted in Otterman & Fraser 1976).

Krämer ., 1938: Die koloniale Entwicklung des Anglo-ägyptischen Sudans, Berlin.

Kung E.C., Bryson R.A. & Lenschow D.H., 1964: Study of a Continental Surface Albedo on the Basis of Flight Measurements and Structure of the Earth's Surface Cover over North America. Monthly Weather Review 92, pp 543 - 564, (quoted in Otterman & Fraser 1976)

Lagrange J-L., 1788: Mecanique Analytique.

Lamprey H.F., 1975: Report on the Desert Encroachment Reconnaissance in Northern, Sudan, 21 October to 10 November 1975. UNESCO/UNEP (mimeo) 16 p.

Landgrebe D.A., 1978: Useful Information from Multispectral Image Data: Another Look. Chapter 7 in Swain & Davis 1978.

Lid-Hjort N. & Mohn E., 1984: A Comparison of Some Contextual Methods in Remote Sensing Classification. Proc. 18th International Symposium on Remote Sensing of Environment, Paris.

Lo C.P., 1984: Chinese Settlement Pattern Analysis Using Shuttle Imaging Radar-A Data. International Journal of Remote Sensing, Vol 5, pp 959-967.

Meillassoux C., (no date) Development or Exploitation: Is the Sahel Famine Good Business?.

Middleton W.E.K. & Mungall A.G. 1972: The Luminous Directional of Snow. Journal Optical Society of America, Vol. 42, No 8, pp 572 - 579 (in Hugli & Frei 1983)

Miller R., 1976: GD3 Long Write-up. CERN Computer Centre. 127 p.

- Monmonier M.S., 1982: Computer-Assisted Cartography - Principles and Prospects. Prentice-Hall, 213 p.
- More W.G., 1974: A Dictionary of Geography, Penguin Books, 246 p.
- NAG (Numerical Algorithms Group Ltd) 1984: NAG Fortran Mini Manual Mark.11. NAG, Oxford.
- Nie N.H., Hull C.H., Jenkins J.G., Steinbrenner K. & Bent D.H., 1975: SPSS Statistical Package for the Social Sciences. McGraw-Hill 670 p.
- Noy-Meir I. & Harpaz Y., 1977: Agro-Ecosystems in Israel. Agro-Ecosystems Vol 4, No 1-2, pp 143-167
- Olsson K., 1984(a): Remote Sensing of Woody Vegetation.- A Quantitative Approach in the Sudanese Drylands. Lund University Dept. of Physical Geography, R.o.N. No: 57. 42 p.
- Olsson K., 1984(b): Long-term changes of Woody Vegetation in N. Kordofan The Sudan. - A Study With Emphasis on *Acacia senegal*. Lund University, Dept. of Physical Geography, Rapport & Notiser No:60
- Olsson K., 1985: Fuelwood Demand and Supply in the Umm Ruwaba/ Er Rahad region in N. Kordofan, the Sudan. Lund University, Dept. of Physical Geography, R.o.N. No. 64. 70 p.
- Olsson L., 1982: Monitoring Land Use and Land Use Appropriateness in the Central Sudan. Proc. International Symposium on Remote Sensing of Environment, First Thematic Conference, Cairo, Egypt. pp 963 - 971
- Olsson L., 1983: Desertification or Climate? Investigation Regarding the Relationship Between Land Degradation and Climate in The Central Sudan. Lund Studies in Geography ser A, No. 60, 36 p.
- Olsson L., 1984(a): DIAPAC (Digital Image Analysis Package) Users Manual, Dept. of Physical Geography, University of Lund,
- Olsson L., 1984(b): Report from a Journey to Northern Kordofan and White Nile Provinces 6th - 22nd of February 1984. report submitted to the World Food Program and Range and Pasture Administration, Khartoum, 6p
- Olsson L., 1984(c): Monitoring the Impact of Rain Fed Agriculture and Grazing on Desertification in the Central Sudan. Working papers Second International Rangeland Congress, Adelaide, South Australia, 1p.
- Olsson L., 1984(d): Monitoring Rangeland Conditions in the Western Sudan Using a Geographical Information System. Proc. LANDSAT-84 Third Australasian Remote Sensing Conference, Brisbane, Queensland, pp. 339-349.

Olsson L., 1985: Integration of Physical and Human Geography in a Geographical Information System. Seminar Proceedings of the Land Management and Survival Workshop, The Scandinavian Institute of African Studies, Uppsala, Sweden.

Olsson L. & Stern M., 1981: Large Area Data Sampling for Remote Sensing Applications and Statistical Analysis of Environment. Lund University Dept. of Physical Geography, R.o.N. No: 49.

Olsson L., Olsson K. & Stern M., 1985: Remote Sensing, GIS and Spatial Models for Planning and Management of Natural Resources. Proceedings of the First Scandinavian Research Conference on Geographical Information Systems. National Defence Research Institute (FOA 3), Linköping. pp 11-20.

Otterman J., 1974: Baring High-albedo Soils by Overgrazing: A Hypothesized Desertification Mechanism. Science Vol 186, pp 531 - 533.

Otterman J. & Fraser R.S., 1976: Earth-Atmosphere System and Surface reflectivities in Arid regions from Landsat MSS Data. Remote Sensing of Environment Vol 5, pp 247 - 266.

Otterman J., Ungar S., Kaufman Y. & Podolak M., 1980: Atmospheric Effects on Radiometric Imageing from Satellites under Low Optical Thickness Conditions. Remote Sensing of Environment Vol. 9, pp 115 129.

Pacheco R. & Dawoud H.A., 1976: Exploratory Soil Survey of North and South Kordofan. Soil Survey Report No. 81, Soil Survey Administration, Wad Medani, Sudan.

Panofsky H.A. & Brier G.W., 1958: Some Applications of Statistics and Meteorology. Pennsylvania State University.

Pollock R.B. & Kanemasu E.T., 1979: Estimating Leaf Area Index of Wheat with Landsat Data. Remote Sensing of Environment, Vol. 8, pp 307 - 312.

Prout H.G., 1877: General report on the Province of Kordofan submitted to Gen. C.P. Stone, Chief of the General Staff, Egyptian Army by Major Prout, March 1876, - Cairo Printing office of the General Staff 1877. (quoted by Hellden 1984).

Pytovskaya N.P., 1974: Albedo of the Earth Atmosphere System for Clear and Overcast Skies. in Atmospheric Radiation Studies (ed. Kondratyev), Israel Program for Scientific Translations, Jerusalem, pp 14 - 27, (quoted in Otteraman & Fraser 1976).

Rapp A., 1974: A Review of Desertization in Africa. Water, Vegetation and Man. SIES Report No 1. NFR, Stockholm, 77p, (also published as Lund University Dept. of Physical Geography, R.o.N. No. 39, 1978).

Rapp A., le Houerou, H. & Lundholm B., 1976: Can Desert Encroachment be Stopped? A Study with Emphasis on Africa. Ecol. Bulletin No. 24, NFR, Stockholm, 241 p.

- Reeves R.G., (ed.) (1975): Manual of Remote Sensing, Vol 2, Glossary. American Society of Photogrammetry, Falls Church, Vi.
- Reeves E.B. & Frankenberger T., 1981: Farming Systems Research in North Kordofan, Sudan. Report No. 1. Dept. of Sociology, College of Agric. Univ. of Kentucky, Lexington, U.S.A. 71 p.
- Reeves E.B. & Frankenberger T., 1982: Farming Systems research in North Kordofan, Sudan. Report No. 2. Dept. of Sociology, College of Agric. Univ. of Kentucky, Lexington, U.S.A. 71 p.
- Reining P., (editor) 1978: Handbook on Desertification Indicators. Americal Association for the Advancement of Science, Washington D.C. 141 p.
- Rich D.C., 1980: Potential Models in Human Geography. Concepts and Techniques in Modern Geography (CATMOG) No. 26, Geo Abstracts, Norwich, U.K., 37 p.
- Richards J.A., 1984: Thematic Mapping from Multitemporal Image Data Using the Principal Components Transformation. Remote Sensing of Environment Vol. 16, pp 35-46.
- Richards J.A., Landgrebe D.A. & Swain P.H., 1982: A Means for Utilizing Ancillary Information in Multispectral Classification. Remote Sensing of Environment, Vol 12, pp 463-477.
- Richards W., 1978: Experiments in Texture Perception. Quoted in Hsu & Burright (1980).
- Richardson A.J. & Wiegand C.L., 1977: Distinguishing Vegetation from Soil Background Information. Photogrammetric Engineering and Remote Sensing, Vol 43, pp 1541 - 1552.
- Robinove C.J., Chavez P.S.(Jr), Gehring D. & Holmgren R., 1981: Arid Land Monitoring Using Landsat Albedo Difference Images. Remote Sensing of Environment, Vol 11, pp 133 - 156.
- Rural Water Corporation: Archive on deep bored wells in Kordofan Provinces, El Obeid.
- Ryan T.A., Joiner L.J. & Ryan B.F., 1981: MINITAB Reference Manual. Pennsylvania State University, 154 p.
- Salama R.B., (no year): Ground Water Resources of Sudan. Rural Water Corporation, Khartoum, Sudan.
- Sandström, K., 1984: Kartläggning av grundvattenförhållandena i ett delområde av provinsen Nord Kordofan, Sudan. M. Sc. thesis No 5 1984, Dept. of Quaternary Geology, University of Lund. (mimeo).
- Schowengerdt R.A., 1983: Techniques for Image Processing and Classification in Remote Sensing. Academic Press, 249 p.
- Shephard D., 1984: Computer Mapping: The SYMAP Interpolation

Algorithm. pp 133 - 146 in Gaile & Willmott 1984.

Statistics Division, 1974, 1977 & 1984: Yearbook of Agricultural Statistics. Dept. of Agricultural Economics, Ministry of Agriculture and Irrigation, Khartoum, Sudan.

Stern M., 1982: Landsat Data for Monitoring Rural Settlement and Population - A Test in the Umm Ruwaba Region, The Sudan. Proc. Int. Symp. on Remote Sensing of Arid and Semi Arid Lands, Cairo.

Stern M., 1984: Landsat Data for Population Estimates - Approaches to Inter-Censal Counts in the Rural Sudan. Adv. Space Res. Vol. 4 No 11, pp 69 - 73.

Stern M., 1985: Census from Heaven? Ph.D. thesis, Dept. of Physical Geography, University of Lund, Sweden.

Stewart J.Q. 1941: An Inverse Distance Variation for Certain Social Influences. Science Vol. 93, pp 89-90.

Stewart J.Q., 1947: Empirical Mathematical Rules Concerning the Distribution and Equilibrium of Population. Geographical Review, Vol 37, pp. 461-485.

Stewart J.Q. & Warntz W., 1958: Macrogeography and Social Science. Geographical Review, Vol 48, pp. 167-184.

Strahler A.H., Logan T.L. & Bryant N.A., 1978: Improving Forest Cover Classification Accuracy from Landsat by Incorporating Topographic Information. Proc. 12th International Symposium on Remote Sensing of Environment, pp. 927-942.

Strahler A.H., Logan T.L. & Woodcock C.E., 1979: Forest Classification and Inventory System Using Landsat, Digital Terrain and Ground Sample Data. Proc. 13th International Symposium on Remote Sensing of Environment, pp. 1541-1557.

Strahler A.H., 1980: The Use of Prior Probabilities in Maximum Likelihood Classification of Remotely Sensed Data. Remote Sensing of Environment, Vol 10, pp 135-164.

Strahler A.H., Estes J.E., Maynard P.F., Mertz F.C. & Stow D.A., 1980: Incorporating Collateral Data in Landsat Classification and Modelling Procedures. Proc. 14th Int. Symp. on Remote Sensing of Environment, Costa Rica.

Sudan Meteorological Department: Meteorological Yearbook 1950 - 1984, and Monthly Rainfall Statistics 1981 - 1985.

Sumner G.N., 1978: Mathematics for Physical Geographers. Edw. Arnold, London, 236 p.

Swain P.H. & Davis S.M., (eds) 1978: Remote Sensing the Quantitative Approach. McGraw-Hill, 396 p.

Thomas R., W., 1977: An Introduction to Quadrat Analysis,

Concepts and Techniques in Modern Geography, Geo Abstracts, Norwich.

Thomas R., W., and Huggett R., J., 1980: Modelling in Geography - A Mathematical Approach, Harper & Row Publishers, London, 338p.

Tom C.H. & Miller L.D., 1980: Forest Site Index Mapping and Modeling. Photogrammetric Engineering and Remote Sensing, Vol 46, pp. 1585-1596

Townshend J. R. G. (Editor), 1981 (a): Terrain Analysis and Remote Sensing. George Allen & Unwin, 232 p.

Townshend J. R. G., 1981 (b): Image Analysis and Interpretation for Land Resources Survey. Chapter 4, in Townshend 1981 (a)

Trilsbach A. & Hulme M., 1984: Recent Rainfall Changes in Central Sudan and their Physical and Human Implications. Trans. Inst. British. Geographers. N.S. Vol 9. pp 280 - 298.

Tucker C.J., 1979: Red and Photographic Infrared Linear Combinations for Monitoring Vegetation. Remote Sensing of Environment, Vol 8, pp 127 - 150.

UN (United Nations), 1977: Desertification: Its Causes and Consequences. Pergamon Press, 448 p.

UNDP & FAO, 1967: Land and Water Use Survey in Kordofan Province, The Sudan, Final Report, FAO Rome 310 p

UNSO (United Nations Sudano Sahelian Office) 1981: Desertification Control and Range Management: An Approach to the Protection and Further Development of the Range Resources in Western Sudan. 60p.

US Department of Agriculture, 1984: Unpublished report on food production/deficit in The Sudan 1984.

US Geological Survey, 1979: Manual on Characteristics of Landsat Computer-Compatible Tapes Produced by the EROS Data Center Digital Image Processing System. U.S. Geological Survey.

Vink A.P.A., 1975: Land Use in Advancing Agriculture. Springer Verlag, New York, 394 p.

Wallen C.C., 1967: Aridity Definitions and their Applicability. Geografiska Annaler Vol 49A pp 367-384.

Warren A., 1970: Dune Trends and their Implications in the Central Sudan. Zeitschrift für Geomorphologie, Supplementband 10, pp. 154 180.

Warren A. & Maizels J.K., 1977: Ecological Change and Desertification. Chapter 3 in UN 1977.

Watson R.M., Tippet C.I., Rizk F., Jolly F. & Beckett J., 1976: Sudan National Livestock Census and Resource Inventory,

Vol 23 & 24 (North and South Kordofan), Sudan Veterinary Research Administration, Ministry of Agriculture, Food and Natural Resources, Khartoum, Sudan.

Watson R.M., Tippet C.I., Rizk F., Jolly F., Beckett J., Scholes V. & Casbon F., 1977: Sudan National Livestock Census and Resource Inventory, Vol 31, Sudan Veterinary Research Administration, Ministry of Agriculture, Food and Natural Resources, Khartoum, Sudan.

Wiegand C.L. & Richardson A.J., 1982: Comparisons Among a New Soil Index and Other Two- and Four-dimensional Vegetation Indices. Proc. 48th Annual Meeting, Amer. Soc. Photogramm. pp. 211-227

WMO (World Meteorological Organization), 1975: Drought, Special Environmental Report No. 5, WMO, Geneva, 113 p.

Zonneveld I.S., 1972: Lectures on Vegetation Science (ecology) and Vegetation Survey. ITC Mimeograph Series. Enschede. (in van Genderen et. al. 1978)

MEDDELANDEN FRÅN LUNDS UNIVERSITETS
GEOGRAFISKA INSTITUTION

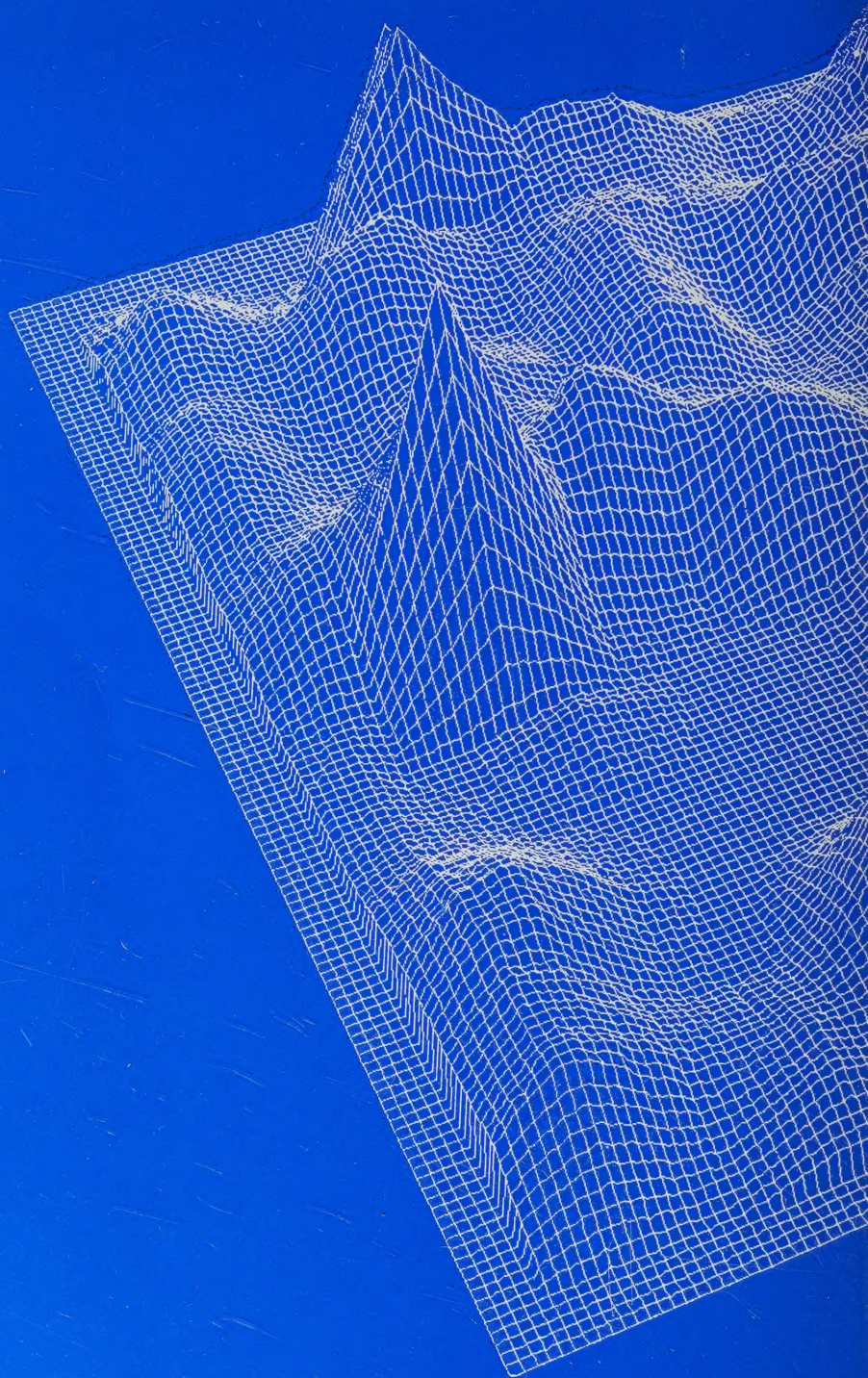
Serie Avhandlingar

- I. *Herman Richter*: Skånes karta från mitten av 1500-talet till omkring 1700. Bidrag till en historisk-kartografisk undersökning. (1929).
- II. *Josef Westin*: Kulturgeografiska studier inom Nätra-, Näske- och Utbyåarnas flodområden samt angränsande kusttrakter. (1930).
- III. *Herman Richter—Wilhelm Norlind*: Orbis Arctoi Nova et Accurata Delineatio Auctore Andrea Bureo Sueco 1626. (1936).
- IV. *Sven Björnsson*: Sommen-Åsundenområdet. En geomorfologisk studie. (1937).
- V. *Arne Sandell*: Tektonik och morfologi inom dalformationen med omgivande urbergsterräng. (1941).
- VI. *Sven Dahl*: Torna och Bara. Studier i Skånes bebyggelse- och näringsgeografi före 1860. (1942).
- VII. *Karl Erik Bergsten*: Isälvsfält kring norra Vättern. Fysisk-geografiska studier. (1943).
- VIII. *Carl Erik Nordenskjöld*: Morfologiska studier inom övergångsområdet mellan Kalmarsslätten och Tjust. (1944).
- IX. *Sven Björnsson*: Blekinge. En studie av det blekingiska kulturlandskapet. (1946).
- X. *Karl Erik Bergsten*: Östergötlands bergslag. En geografisk studie. (1946).
- XI. *Tor Holmquist*: Den halländska vinterfiskehamnsfrågan. (1947).
- XII. *Olof Ångeby*: Landformerna i nordvästra Jämtland och angränsande delar av Nord-Trøndelag. (1947).
- XIII. *Axel Wennberg*: Lantbebyggelsen i nordöstra Östergötland 1600-1875. (1947).
- XIV. *Lars Bjerning*: Skånes jord- och stenindustri. Dess utveckling, lokalisering och betydelse ur näringsgeografisk synvinkel. (1947).
- XV. *Allan Weinhausen*: Norbergs bergslag samt Gunnilbo och Ramnäs till omkring 1820. Studier i områdets närings- och bebyggelsegeografi. (1947).
- XVI. *Helge Stålberg*: Smålands skogs- och träförädlingsindustrier. En näringsgeografisk studie. (1947).
- XVII. *Folke Lägner*: Veteodlingen i södra och mellersta Sverige. (1949).
- XVIII. *Yngve Nilsson*: Bygd och näringsliv i norra Värmland. En kulturgeografisk studie. (1950).
- XIX. *Olof Ångeby*: Evorsionen i recenta vattenfall. (1951).
- XX. *Karl Erik Bergsten*: Sydsvenska födelseortsfält. (1951).
- XXI. *Folke Lägner*: Valmanskåren på Skånes landsbygd 1911-1948. (1952).
- XXII. *Olof Nordström*: Relationer mellan bruk och omland i östra Småland 1750-1900. (1952).

- XXIII. *Arvid Bergdahl*: Israndsbildningar i östra Syd- och Mellansverige med särskild hänsyn till åsarna. (1953).
- XXIV. *Sven E Behrens*: Morfometriska, morfogenetiska och tektoniska studier av de nordvästskånska urbergsåsarna, särskilt Kullaberg. (1953).
- XXV. *Torsten Hägerstrand*: Innovationsförloppet ur korologisk synpunkt. (1953).
- XXVI. *Gunhild Weimarck*: Studier över landskapets förändring inom Lönsboda, Örkeneds socken, nordöstra Skåne. (1953).
- XXVII. *Ingemar Larsson*: Structure and Landscape in Western Blekinge, Southeast Sweden. (1954).
- XXVIII. *Sven Godlund*: Busstrafikens framväxt och funktion i de urbana influensfälten. (1954).
- XXIX. *Folke Längnert*: Syd- och mellansvenska växtföljder. Del I. De äldre brukningssystemens upplösning under 1800-talet. (1955).
- XXX. *Olof Ångeby*: Toppkonstans, erosionsytor och passdalar i Jämtland och Trøndelag. (1955).
- XXXI. *Gunnar Johnsson*: Glacialmorfologiska studier i södra Sverige. (1956).
- XXXII. *Folke Längnert*: Syd- och mellansvenska växtföljder. Del II. 1900-talet. (1956).
- XXXIII. *Olof Nordström*: Befolkningsutveckling och arbetskraftsproblem i östra Småland 1800-1955. (1957).
- XXXIV. *Sven Godlund*: Befolkning—regionsjukhus—resmöjligheter—regioner. (1958).
- XXXV. *Elis Pålsson*: Gymnasiers rekrytering och lokalisering. (1958).
- XXXVI. *Harald Svensson*: Glaciation och morfologi. En glacialgeografisk studie i ett tvärsnitt genom Skanderna mellan södra Helgelandskusten och Kultsjödalen. (1959).
- XXXVII. *Erik Ljungner*: Nahuel Huapi. Ein geographischer Querschnitt durch die Anden in Patagonien. (1959).
- XXXVIII. *Nils Lewan*: Om pendling mellan bostad och arbetsplats. En undersökning med material från sydvästra Skåne. (1960).
- XXXIX. *Åke Mattsson*: Morphologische Studien in Südschweden und auf Bornholm über die nichtglaziale Formenwelt der Felsenskulptur. (1962).
- XL. *Stig Nordbeck*: Framställning av kartor med hjälp av siffermaskiner. (1964).
- XLI. *Olof Nordström*: Svensk glasindustri 1550-1960. (1962).
- XLII. *Jan Davidsson*: Littoral Processes and Morphology on Scandian Flatcoasts. (1963).
- XLIII. *Martin Markgren*: Detaljmorfologiska studier i fast berg och blockmaterial. Geomorfologisk studie inom Fennoscandia med Skåne. (1962-1963).
- XLIV. *Martin Markgren*: Geomorphological Studies in Fennoscandia. II. Chute Slopes in Northern Fennoscandia. A. Regional Studies. (1964).
- XLV. *Martin Markgren*: Geomorphological Studies in Fennoscandia. II. Chute Slopes in Northern Fennoscandia. B. Systematic Studies. (1964).
- XLVI. *Lennart Améen*: Stadsbebyggelse och domänstruktur. (1964).
- XLVII. *Arvid Bergdahl*: Det glaciala landskapet. (1961).

- XLVIII. *Olof Nordström—Solweig Mårtensson: Turism på Öland. (1966).*
- XLIX. *Jan O Mattsson: The Temperature Climate of Potato Crops. (1966).*
L. *Nils Lewan: Landsbebyggelse i förvandling. (1967).*
- LI. *Gösta Nordholm: Skånes äldre ekonomiska geografi. (1967).*
- LII. *Sven Godlund—Torsten Hägerstrand—Bengt Swanström: Samhällsutvecklingen och samhällsplaneringen. (1967).*
- LIII. *Tor Fr Rasmussen: Storbyutvikling og arbeidsreiser. (1966).*
- LIV. *Erik Fagerlund—Harald Svensson—Sven Lindqvist m fl: Infrarödtermografi. Principer och naturgeografiska tillämpningar. (1967).*
- LV. *Lars Eldblom: Structure foncière, organisation et structure sociale. (1968).*
- LVI. *Knut Norborg: Jordbruksbefolkningen i Sverige. (1968).*
- LVII. *Gunhild Weimarck: Ulfshult (1968). Out of print.*
- LVIII. *Rune Järvenstedt—Sven Lindqvist—Jan O Mattsson m fl: Televisionssystem i naturgeografisk forskning. (1968).*
- LIX. *Arne Jakobsson: Omflyttningen i Sverige 1950-1960. (1969).*
- LX. *Åke Hillefors: Västsveriges glaciala historia och morfologi. (1969). Out of print.*
- LXI. *Sven Lindqvist: Bebyggelseklimatiska studier. (1970).*
- LXII. *Torsten Hägerstrand—Gunnar Törnqvist m fl: Urbaniseringen i Sverige. (SOU 1970:14).*
- LXIII. *Bengt Sahlberg: Interregionala kontaktmönster. Personkontakter inom svenskt näringsliv — en flygpassagerarstudie. (1970).*
- LXIV. *Björn Hedberg: Kontaktsystem inom svenskt näringsliv. En studie av organisationers externa personkontakter. (1970).*
- LXV. *Mats G Engström: Regional arbetsfördelning. Nya drag i förvärvsarbets geografiska organisation i Sverige. (1970).*
- LXVI. *Torsten Persson: Geomorphological Studies in the South-Swedish Highlands. (1972).*
- LXVII. *Dewitt Davis Jr.: A factorial ecology of Malmö 1965. The social geography of a city. (1972). Out of print.*
- LXVIII. *Zoltan Petery: Studier i svensk regionalplanering. Regionalplanering enligt byggnadslagen i mindre regioner. (1972). Out of print.*
- LXIX. *Tommy Book: Stadsplan och järnväg i Norden. (1974).*
- LXX. *Hans Abrahamson: Studier i jordbrukets omstrukturering. (1974).*
- LXXI. *Christer Persson: Kontaktarbete och framtida lokaliseringsförändringar. (1974).*
- LXXII. *Ulf Helldén: Karst. En studie av Artfjällets karstområde samt jämförande korrosionsanalyser från Västspetsbergen och Tjeckoslovakien. (1974).*
- LXXIII. *János Szegő: Befolkningstäthet, markanvändning, planering (vol 1 o 2). (1974).*
- LXXIV. *Raul Nino Guerrero: Rural to Urban Drift of the Unemployed in Colombia. (1975).*
- LXXV. *Ulf Erlandsson: Företagsutveckling och utrymmesbehov. (1975).*
- LXXVI. *Sture Öberg: Methods of Describing Physical Access to Supply Points. (1976).*
- LXXVII. *Bo Lennorp: Paths in Space-time Environments. A Time-geographic Study of Movement Possibilities of Individuals. (1976).*
- LXXVIII. *Richard Åhman: Palsar i Nordnorge. En studie av palsars morfologi, utbredning och klimatiska förutsättningar i Finnmarks och Troms fylke. (1977).*

- LXXIX. *Björn Gyllström*: The Organization of Production as a Space-modeling Mechanism in Underdeveloped Countries. (1977).
- LXXX. *Anders Järnegren—Fosco Ventura*: Tre samhällens förändringshistoria. Exploatering av den fysiska miljön i historisk belysning. (1977).
- LXXXI. *Tommy Book*: Stadsplan och järnväg i Storbritannien och Tyskland. (1978).
- LXXXII. *Jan O Mattsson—Leif Börjesson*: Lokalklimatiska temperaturstudier inom ett skånskt fruktodlingsdistrikt med särskilt beaktande av frostläntheten. (1978).
- LXXXIII. *Bjørn Terje Asheim*: Regionale ulikheter i levekår. (1979).
- LXXXIV. *Solveig Mårtensson*: On the Formation of Biographies in Space-time Environments. (1979).
- LXXXV. *Erik Wallin*: Vardagslivets generativa grammatik — Vid gränsen mellan natur och kultur. (1980).
- LXXXVI. *Reinhold Castensson*: Välja för framtid — om markanvändningsval och förtroendemannainflytande i kommunal planering. (1980).
- LXXXVII. *Kerstin Montal*: Industri och vatten. Den vattenförorenande industrins lokaliseringsproblem i Malmöhus län. (1980).
- LXXXVIII. *Tommy Carlstein*: Time Resources, Society and Ecology. (1980).
- LXXXIX. *Jonas Åkerman*: Studies on periglacial geomorphology in West Spitsbergen. (1980).
- XC. *Leif Engh*: Karstområdet vid Lummelunds bruk, Gotland, med speciell hänsyn till Lummelundagrottan. (1980).
- XCI. *Karna Lidmar-Bergström*: Pre-quaternary Geomorphological Evolution in Southern Fennoscandia. (1982).
- XCII. *Lars-Olof Olander*: Staten, kommunerna och servicen. (1984).
- XCIII. *Bo Malmström—Owe Palmér*: Glacial och periglacial geomorfologi på Varangerhalvön, Nordnorge. Geomorfologisk kartering med analys av glaciala former och blockhav. (1984).
- XCIV. *Franz-Michael Rundquist*: Hybrid Maize Diffusion in Kenya. (1984).
- XCV. *Girma Yadeta*: Dynamic Processes of Development in Marginal Areas. (1985).
- XCVI. *Anders Sporrek*: Food Marketing and Urban Growth in Dar Es Salaam. (1985).
- XCVII. *Rolf Nyberg*: Debris Flows and Slush Avalanches in Northern Swedish Lapland. Distribution and Geomorphological Significance. (1985).
- XCVIII. *Lennart Olsson*: An Integrated Study of Desertification — Applications of Remote Sensing, GIS and Spatial Models in Semi-arid Sudan. (1985).



ISBN 91-7222-975-6